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SOIL-MOISTURE MEASUREMENT WITH THE FIBERGLAS INSTRUMENT

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SOIL-MOISTURE MEASUREMENT WITH THE FIBERGLAS INSTRUMENT

The introduction of electrical instruments for determining the march of soil moisture has given great impetus to all studies in which such knowledge is essential. By permitting a continuous record at one point, these instruments have obviated the difficulties inherent in direct sampling--the immense expenditure of labor, the often inexplicable variations in the samples, and the impossibility of taking a sample without destroying the sampling point.

These benefits are not without their price. Very careful installation and rather elaborate calibration of the units are fundamental to their successful use. Since established techniques for accomplishing these ends remain to be developed, investigators must still rely on hard-won experience, usually their own. This paper records such experience with one type of these instruments, the fiberglas-soil moisture unit and ohmmeter. About 210 fiberglas units have been installed near Vicksburg, Mississippi, in soils of loessial and alluvial origin ranging in texture from silt loam to clay. The installation, made in April 1951 and still in operation, probably represents the largest single project of its kind to date.

The paper consists of five articles, each more or less independent of the others. The first concerns a simple comparison of the four principal types of electrical soil-moisture units; it points out that there is little essential difference in their performance but notes certain convenient features of the fiberglas unit. The second and third articles describe devices helpful in placing the fiberglas units in the ground and in providing reliable and convenient means of taking readings. Calibration of the units--that is, determining the relationship between the readings on the ohmmeter and the actual moisture content of the soil--is discussed in the fourth and fifth articles. The fourth article suggests reasons why laboratory calibration of the units was not useful at Vicksburg. The fifth describes field calibration procedures that have proven successful and gives recommendations for installing the units and conducting the study.

COMPARISON OF FOUR TYPES OF ELECTRICAL RESISTANCE INSTRUMENTS FOR MEASURING SOIL MOISTURE

E. H. Palpant and H. W. Lull

Four types of electrical resistance instruments for measuring soil moisture in the field have been developed and put to use during the past several years. The first was the plaster of paris block described by Bouyoucos and Mick (2) [1/] in 1940. Seven years later the fiberglas unit was introduced by Colman (5). In 1949, Bouyoucos brought out a fabric unit made of nylon (4). More recently Youker and Dreibelbis (7) described a fourth type made of both plaster of paris and fiberglas.

Each of these units operates on the principle that resistance to the passage of an electrical current through the unit will depend on its moisture content. Buried in the soil, the porous material of the unit wets and dries along with the soil around it, and the changes in moisture content affect the electrical conductivity of the unit. Wires lead from the unit to the surface of the ground, where the resistance of the unit is read with a meter. To convert resistance readings to soil moisture values requires calibration of the units in the soil being studied.

The four units are pictured in figure 1. Dimensions and details will be found in table 1. In the fiberglas unit, electrical resistance is measured between two monel metal screens separated by two layers of fiberglas cloth, the whole enclosed in three layers of the same material and bound in a monel metal case that is spot-welded at the edges. The fiberglas unit differs from all others in that it contains a thermistor, thus permitting soil temperature measurements by which resistances may be corrected to a common temperature. The resistance between the electrodes is read with a battery-operated alternating-current microammeter.

1/ Underscored numbers in parentheses refer to Literature Cited, p. 15.

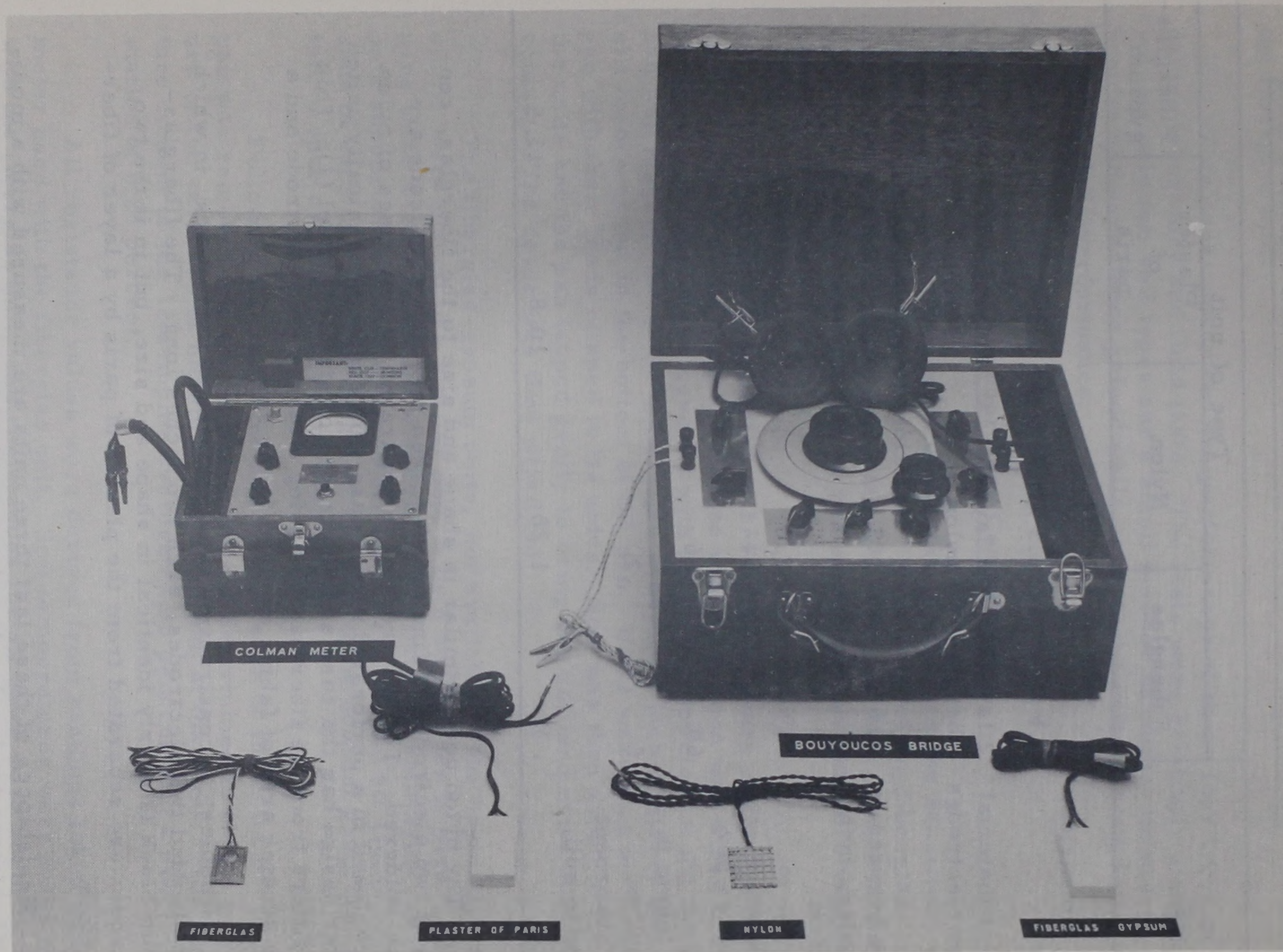

Figure 1.--Soil moisture units and meters. (Photo by Waterways Experiment Station, Corps of Engineers)

Table 1. --Dimensions and details of electrical soil-moisture units

Item	Type of unit			
	Fiberglas	Nylon	Plaster of paris	Fiberglas-gypsum
Outside dimension, inches	1.5 x 1 x .12	1.5 x 1.25 x .12	2.5 x 1.38 x .5	2.5 x 1.5 x .5
Absorbent material between electrodes	2 layers fiberglas	1 layer nylon	Plaster of paris	Fiberglas, plaster of paris
Distance between electrodes, inch	.03	.03	.88	.75
Electrodes:				
Area, sq. in.	.39	2.0	...	...
Length, in.	...	...	2.0	.25 - .5
Mesh, wires per sq. in.	60	96	...	...
Area of fabric in unit, sq. in.	5	2	...	...
Area of absorbent exposed to soil, sq. in.	.20	1.20	10.8	11.5

The nylon unit, similar in shape and size to the fiberglas, consists of two electrodes of fine metal screen to which wire leads are silver-soldered. The electrodes are separated by wrappings of nylon and enclosed in a perforated nickel case with edges mechanically united. A later design has the case and electrodes of stainless steel (1). This unit differs from the fiberglas by having a larger grid electrode and a much greater area of fabric exposed to the soil.

Simplest in construction is the plaster of paris block, in which are embedded two electrodes, each two inches long. The fiberglas-gypsum block is nearly identical in shape and size, but in it the two electrodes are separated from the plaster of paris by a layer of fiberglas cloth.

Resistances of these last three units are measured with a modified Wheatstone bridge developed originally for use with the plaster of

paris block (3). They may also be determined with the meter used with the fiberglas unit.

This paper describes the performance of these four types of units during laboratory and field tests. The tests were relatively simple, involving only two soil types and a small number of units. However, the results and experience gained while using these units permit some evaluation of their performance.

Laboratory Comparison

Laboratory tests were conducted to compare the sensitivity of the units to changes in soil moisture. Four each of the fiberglas, nylon, and plaster of paris units were placed in a pan of soil. The soil was then wetted and measurements of resistance and weight were taken periodically as it dried.

The pan was constructed of 1/4-inch hardware cloth; dimensions were 8 by 6 by 2-1/2 inches. Bronze window screen was wired against the inside of the pan and covered with paper handtowels. A top for the pan was made of the same materials. About 3/4 inch of sieved Grenada silt loam was put in the bottom of the pan. Units were then set in the pan with their leads clipped to its sides. Soil was then added to cover the units and the pan tapped gently to bring the soil and units into good contact. The cover was then wired on.

The fiberglas-gypsum units, not available at the beginning of the study, were placed in a similar pan, 6 by 6 by 3 inches in size. Both pans were wetted from below with distilled water to saturation and set on a support that permitted free air movement around all sides. Resistance of each unit and the weight of the pan to the nearest gram was obtained once or twice a day for seven days.

Following this test, the soil around each of the units in the larger pan was removed and its moisture content determined to obtain a measure of the variation of moisture within the pan at that time. The moisture content of the 12 samples averaged 2.30 percent with a standard deviation of 0.25 percent.

All resistance values were derived from readings taken with the meter used with the fiberglas unit. Soil temperatures were measured with the fiberglas unit, and resistances for all units were corrected on the basis of these values to 60° F.

Mean drying curves for the replicates of each type of unit are given in figure 2. These curves are fairly typical in shape. The fiberglas curve, for instance, has the elements of the linked-sigmoid shape reported by Colman and Hendrix (6). The nylon curve closely approximates a curve obtained by Bouyoucos and Mick for Dunkirk silt loam (4). The shape of the plaster of paris curve resembles those previously reported for this unit, though resistances at field capacity and wilting point are both higher than the usual values for these points (3). The fiberglas-gypsum curve is more curvilinear than those presented by Youker and Dreibelbis (7) for Keene silt loam.

From the shapes of the curves, it is apparent that the fiberglas, nylon, and fiberglas-gypsum units give an increase of resistance with decrease of moisture content throughout the range of moisture content encountered. The plaster of paris unit shows little change in resistance when the soil moisture is greater than field capacity, a characteristic of this unit (2). Resistances in ohms at approximate points of saturation, field capacity, midway between field capacity and wilting point, and wilting point are given in table 2.

Table 2. --Resistance of soil moisture units at selected soil moisture contents

Soil moisture content (percent)	Unit			
	Fiberglas	Nylon	Plaster of paris	Fiberglas-gypsum
	Ohms			
34 (saturation)	985	10,825	890	3,650
28 (field capacity)	1,780	34,500	960	5,500
18 (midway)	4,000	730,000	1,500	8,800
7 (wilting point)	125,000	4,000,000	280,000	330,000

Nylon units had the greatest range of resistance, and then the fiberglas-gypsum, plaster of paris, and fiberglas units. Variation of the four replicates of each type was greatest among the nylon units, and

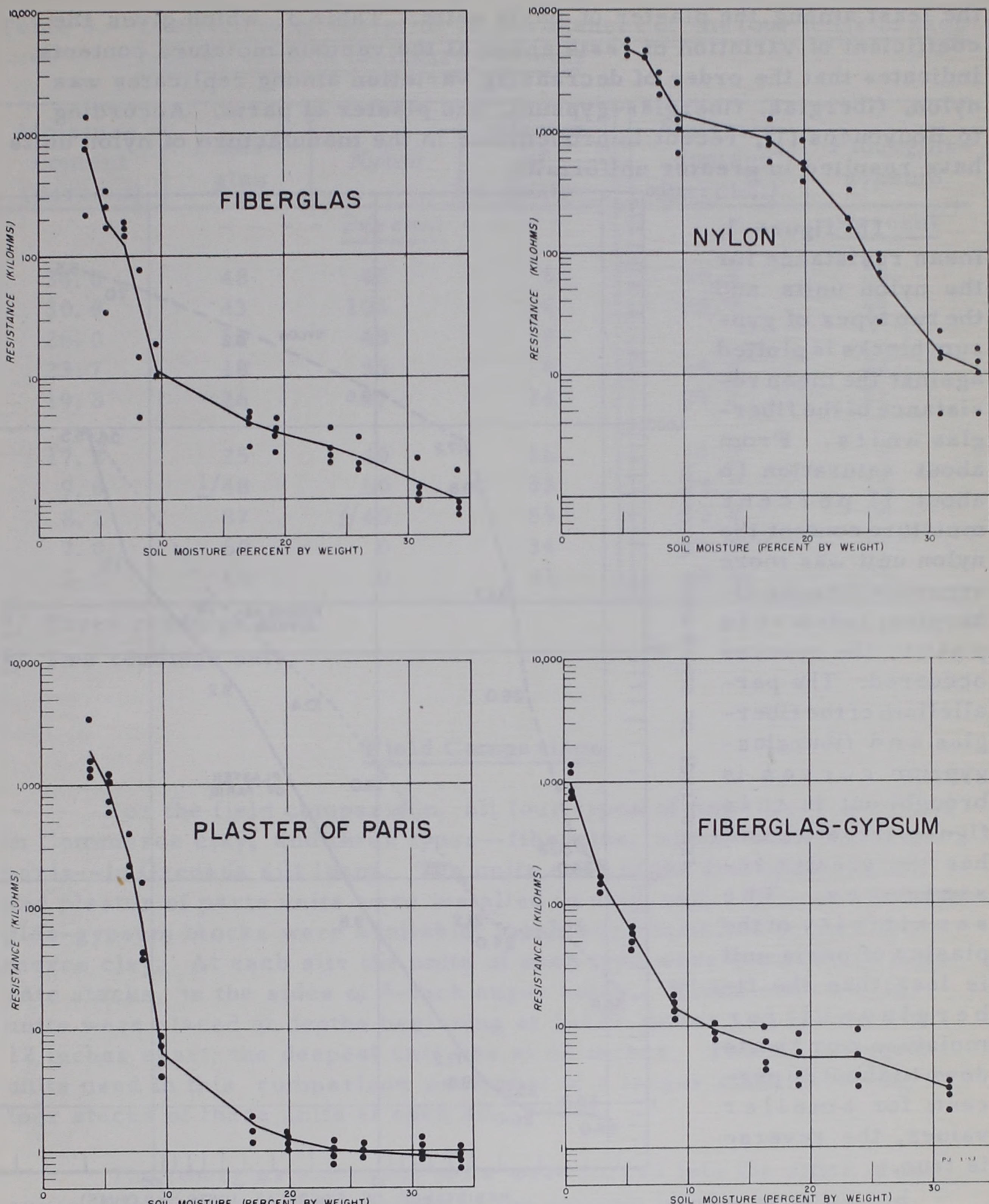

Figure 2.--Drying curves for four types of soil-moisture units. For each chart, resistance was read on four soil units at the same time that the moisture content of the soil was ascertained by weighing (coupled with subsequent oven-drying).

the least among the plaster of paris units. Table 3, which gives the coefficient of variation of resistances at the various moisture contents, indicates that the order of decreasing variation among replicates was nylon, fiberglas, fiberglas-gypsum, and plaster of paris. According to Bouyoucos (1), recent improvements in the manufacture of nylon units have resulted in greater uniformity.

In figure 3, mean resistance for the nylon units and the two types of gypsum blocks is plotted against the mean resistance of the fiberglas units. From about saturation to about 17 percent moisture content the nylon unit was more sensitive than the fiberglas; below this point, the reverse occurred. The parallelism of the fiberglas and fiberglas-gypsum curves is brought out in this figure; the latter unit has the greater resistances. The sensitivity of the plaster of paris unit is less than the fiberglas unit for moisture contents down to about 20 percent; for smaller values, the reverse is true.

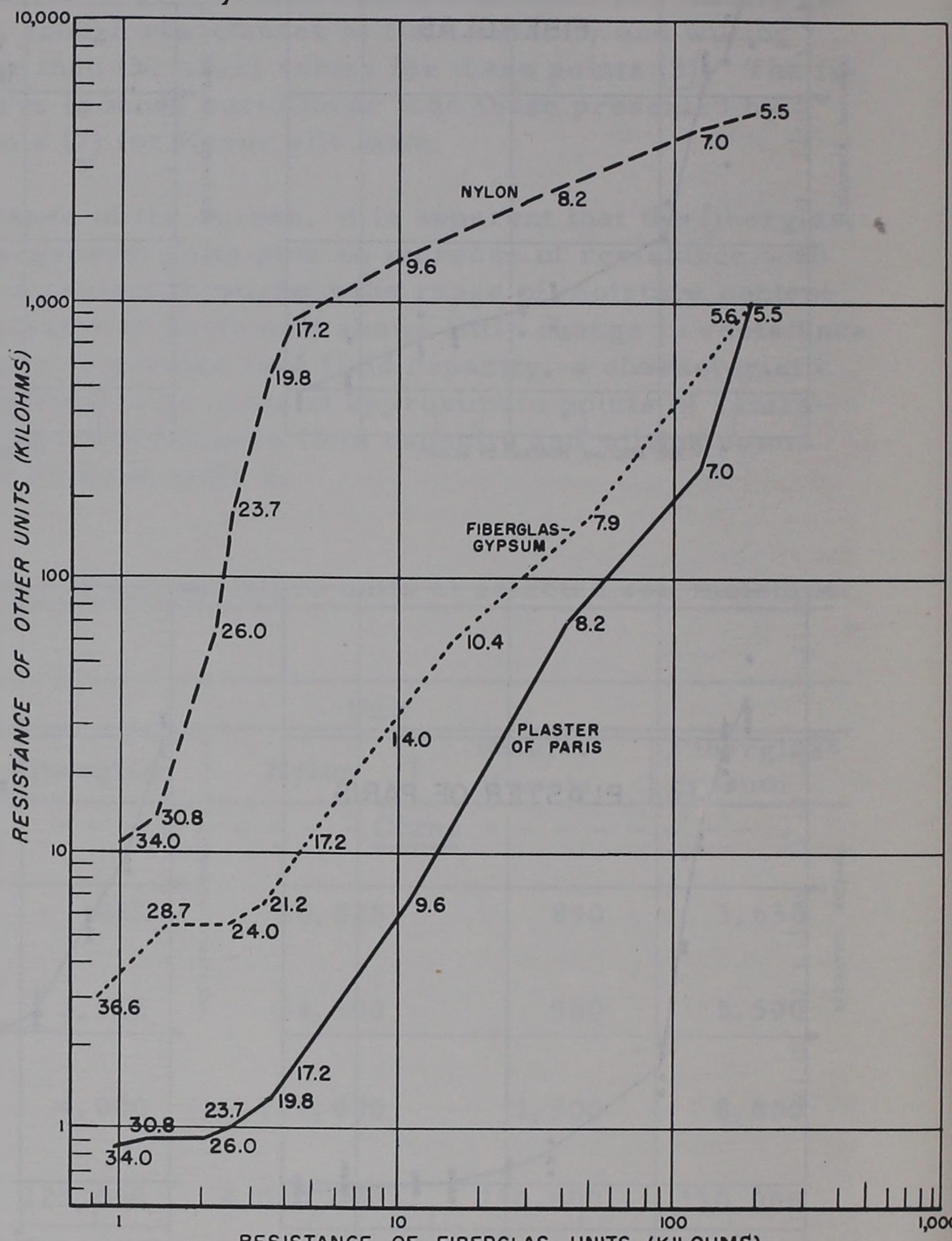

Figure 3.--Resistances of the fiberglas unit compared to resistances of other units at equivalent moisture content. Values on the curves are moisture percents.

Table 3.--Coefficient of variation of resistances of the four units of each type at various moisture contents

Moisture content (percent)	Fiber-glas	Nylon	Plaster of paris	Moisture content (percent)	Fiberglas-gypsum
	- - - -	Percent	- - - -		Percent
34.0	48	45	5	36.4	28
30.8	43	108	4	28.7	49
26.0	34	48	8		
23.7	18	53	4	24.0	44
19.8	26	37	14	21.2	22
17.2	25	40	16	17.2	8
9.6	1/48	60	33	14.0	15
8.2	87	2/40	85	10.4	10
7.0	60	0	34	7.9	13
5.5	65	0	41	5.6	25

1/ Three readings only.

2/ Two readings only.

Field Comparison

For the field comparison, all four types of units were installed in Commerce clay, and three types--fiberglas, nylon, and plaster of paris--in Grenada silt loam. Ten units each of the fiberglas, nylon, and plaster of paris units were installed in each soil. Only seven fiberglas-gypsum blocks were available; these were installed in the Commerce clay. At each site the units of each type were installed in separate stacks, in the sides of 5-inch auger holes. Within each stack, units were placed at depths beginning at 1-1/2 inches and spaced 3 to 12 inches apart; the deepest unit was at 42 inches. The ten fiberglas units used in this comparison were part of a larger study involving four stacks of these units at each site.

The fiberglas and nylon units were forced into the sides of the auger holes in a vertical position. The gypsum blocks were placed horizontally in the hole itself. The soil was replaced in the holes to as near the original density as possible. Daily readings were taken for a period of ten months with the meter designed for use with the fiberglas units.

The daily record of each of the units was plotted in terms of ohms resistance. Variations in the soil moisture record (brought about by soil differences and inherent variations in the response of each unit of each type to changes in soil moisture content) made absolute comparisons of resistances impossible. Instead, units were compared in the light of trends of the daily resistances, such as responses to rainfall or to periods of drying.

These trends indicated similar performance of units at both sites. The similarities can be illustrated from the records of units installed at 1-1/2 and at 30 or 42 inches in the Commerce clay. At this site, the stacks of nylon, plaster of paris, and fiberglas-gypsum units were about two feet apart. The nearest stack of fiberglas units was about 20 feet from these.

The daily resistance record of the four different units for the three depths in the Commerce clay is charted in figure 4. Rainfall, together with the soil moisture (as determined from the 4 stacks of fiberglas units) for the 1-1/2- and 42-inch depths, is also given in this figure.

The summer data (fig. 4A-B) include about a two-month period beginning on July 3, when rainfall had wet the soil, and continue through a period of summer drying interrupted, at the 1-1/2-inch depth, by four rainfalls. None of these rainfalls penetrated to the 30- or 42-inch depths. The two-month winter record (fig. 4C-D) illustrates typical winter conditions of frequent rainfall and wet soil.

Summer data for the 1-1/2-inch depths (fig. 4A) show the immediate response of all four units to changes in soil moisture. Except for one instance, resistances of the units follow the same trends during wetting and drying periods. The exception was the signal response of the fiberglas unit to the 0.16 inch of rainfall of August 5. This may have been due to water entering a soil crack, such as are common when this soil dries, and wetting the unit. Of the three other fiberglas units installed at the same 1-1/2-inch depth at the experimental area, two responded in a similar manner while the third showed no effect of the rainfall. In this case, soil moisture content was estimated from the response of the third unit.

Summer data for the 42-inch depth (fig. 4B) again show similarity in the trend of the units. Because summer rainfall did not penetrate to this depth, the entire period was one of drying with a progressive increase in resistance. In both figures 4A and B there is considerable variation in the resistance readings of the dry soil for

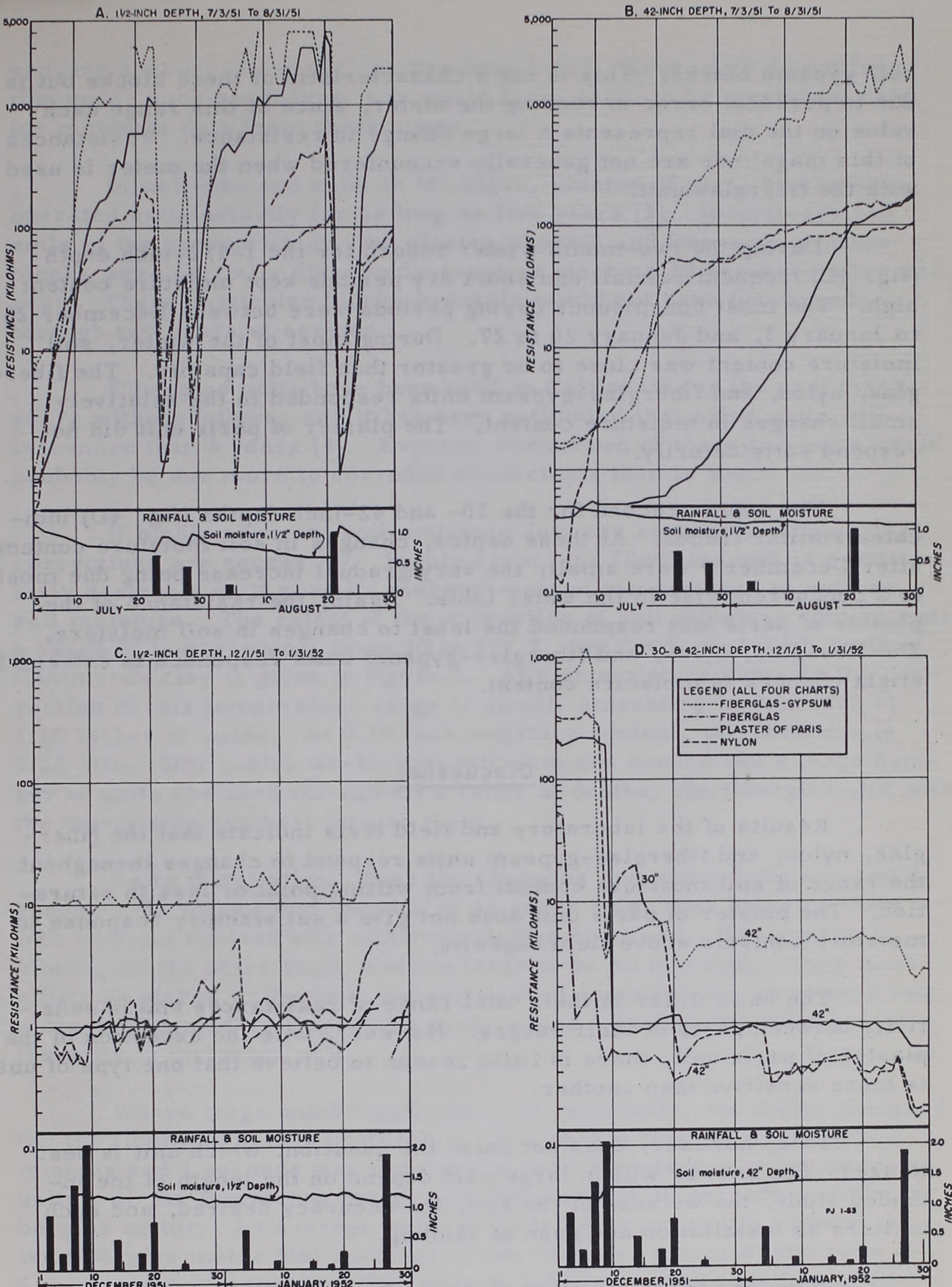

Figure 4.--Daily resistance, soil moisture contents, and rainfall, during summer and winter seasons, Commerce clay soil.

both gypsum blocks. This is not a characteristic of these blocks but is due to personal error in reading the meter, since at this range each value on the dial represents a large change in resistance. Resistances of this magnitude are not generally encountered when the meter is used with the fiberglas unit.

During the two-month winter record for the 1-1/2-inch depth (fig. 4C) frequent rainfall and short dry periods kept moisture content high. The most conspicuous drying periods were between December 26 to January 3, and January 20 to 27. During most of the winter, soil moisture content was close to or greater than field capacity. The fiberglas, nylon, and fiberglas-gypsum units responded to the relatively small changes in moisture content. The plaster of paris unit did not respond satisfactorily.

The winter record for the 30- and 42-inch depths (fig. 4D) indicates similar trends. At these depths, changes in soil moisture content after December 9 were small, the very gradual increase being due mostly to a concurrent rise in the water table. Again, the resistance of the plaster of paris unit responded the least to changes in soil moisture. The fiberglas, nylon, and fiberglas-gypsum units responded to extremely slight changes in moisture content.

Discussion

Results of the laboratory and field tests indicate that the fiberglas, nylon, and fiberglas-gypsum units respond to changes throughout the range of soil moisture content from wilting point or less to saturation. The plaster of paris unit does not give a satisfactory response to moisture contents above field capacity.

The units differ in their total range of resistances and in sensitivity between parts of their ranges. However, with the exception of the plaster of paris unit, there is little reason to believe that one type of unit is more sensitive than another.

This, however, does not solve the question, which unit is best to use? The answer will in large part depend on the length of the intended study, the wetness of the soil, the accuracy desired, and such matters as installation and ease of reading.

In regard to the first two factors, Bouyoucos and Mick (3) state that waterlogged soils reduce the useful life of the blocks to a single

growing season. However, as has been noted, these units do not function under such conditions, nor would there seem to be much real need for moisture data from these areas.

In well-drained soils in Michigan, plaster of paris blocks have operated satisfactorily for as long as five years (3). In well-drained soils in the present study, the plaster of paris and fiberglas-gypsum blocks were partially dissolved--some as much as 30 percent--after one year. These particular blocks probably would not have functioned through two years of service.

Fiberglas units have been used in California for the past three years without failure, and it has been estimated that nylon units will last more than 5 years (4). Eventual breakdown of these two units would probably be due more to corroded connections than to wear.

If highly accurate soil moisture data are required, temperature corrections are necessary. In this event, the fiberglas unit is particularly desirable as it permits measurement of temperature as well as soil moisture. The extent of the correction of soil moisture content over a range of temperatures from 30 to 90° F. for the 0- to 3-inch depth of Commerce clay is given in figure 5. At high moisture contents the correction in this temperature range is small, amounting to 0.05 inch at 1.20 inches of water. At 0.70 inch moisture content, the variation is 0.22 inch. Obviously, where accurate data are needed and a large number of units are used throughout a range of depths, the fiberglas unit with the thermistor can best furnish them.

As to installation. Both the fiberglas and nylon units are small enough to be forced into the side of an auger hole, thus bringing them into intimate contact with relatively undisturbed soil. The gypsum blocks, on the other hand, are too large to be so inserted. They must either be placed in the hole and soil packed around them, or pushed into a crevice formed by a specially made wedge. Such installation leaves the units in disturbed soil.

Where large numbers of units are read daily, the meter designed for the fiberglas unit is preferable. In a recent test, an average of 4 minutes and 3 seconds was required to read resistances of ten fiberglas units with the Bouyoucos bridge, as compared to 36 seconds with the fiberglas meter. An average of 50 seconds was required to convert the ten fiberglas meter dial readings to resistances, giving a total time of 1 minute and 26 seconds. The ratio of 2.83 to 1 could possibly be reduced somewhat with more experienced observers using the bridge.

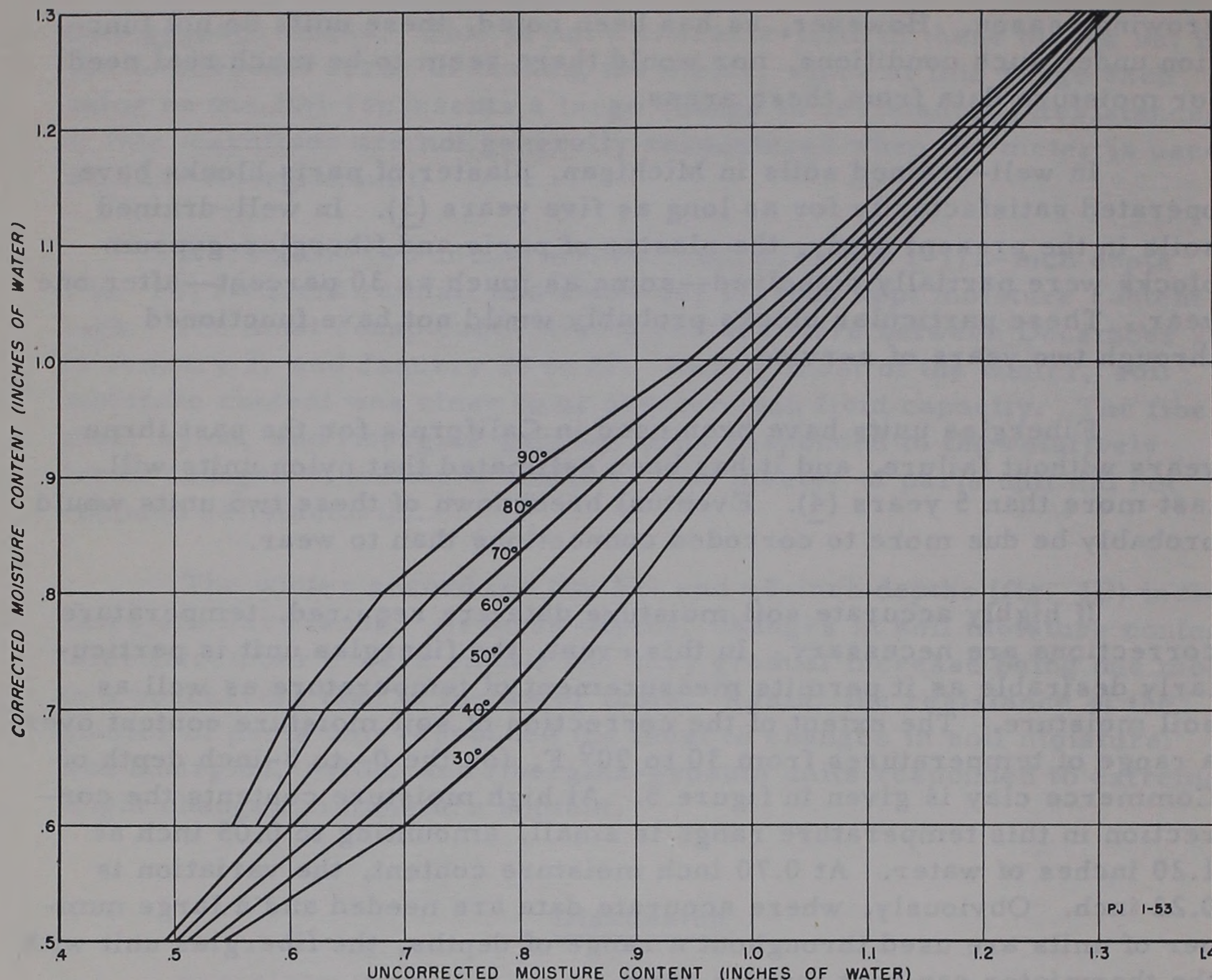

Figure 5. --Effect of temperature (degrees Fahrenheit) on determination of moisture content, for the 0-3 inch soil depth in Commerce clay.

Which unit, then, is the best to use? The fiberglas and nylon units are the most durable. Where accuracy demands correction for temperature, the fiberglas unit is the most convenient, otherwise all units are reasonably accurate. And, as just noted, the smaller units have some advantage in installation. The meter supplied for use with the fiberglas unit permits more rapid reading and is easier to handle. Within their limitations, all four types of units respond similarly to changes in soil moisture.

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AN INSERTER FOR FIBERGLAS SOIL-MOISTURE UNITS

E. H. Palpant

An inherent difficulty in the use of any electrical soil-moisture unit is the soil disturbance resulting from installation.

At the Vicksburg Infiltration Project, where fiberglas units are used, disturbance was kept to a minimum by inserting the units into the side wall of an auger hole. To this end, a device had to be constructed that could be lowered into a 4-3/8-inch auger hole to insert the unit. The device[1/] is built on the same principle as the scissors-type auto jack (fig. 1). With modification of the unit holder, it can be used with the nylon unit as well as the fiberglas.

Construction

Construction procedures are given below; the numbers in parentheses refer to items illustrated in figure 2. Table 1 lists the parts. The unit-holder assembly (shown separately in fig. 2) is the only part which may require machine shop equipment.

1. Take four 6-inch strap hinges and cut 4-1/8 inches from one strap of each; then cut 5 inches from the remaining strap.

2. Cut 1-1/2 inches from each strap of the 4-inch hinge.

3. Braze or weld the 5 strap hinges into the positions shown in the side view in figure 2.

4. Drill a 1/2-inch hole on-center where the 1-inch straps overlap and are welded. This permits passage of the actuating rod. Drill two holes for no. 10 machine screws as shown in figure 2.

5. Drill and tap two holes in each of the two loose straps of the strap-hinge frame, as shown in figure 2, for

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1/ The idea was suggested by C. E. Englehorn, U. S. Soil Conservation Service, Manhatten, Kansas.

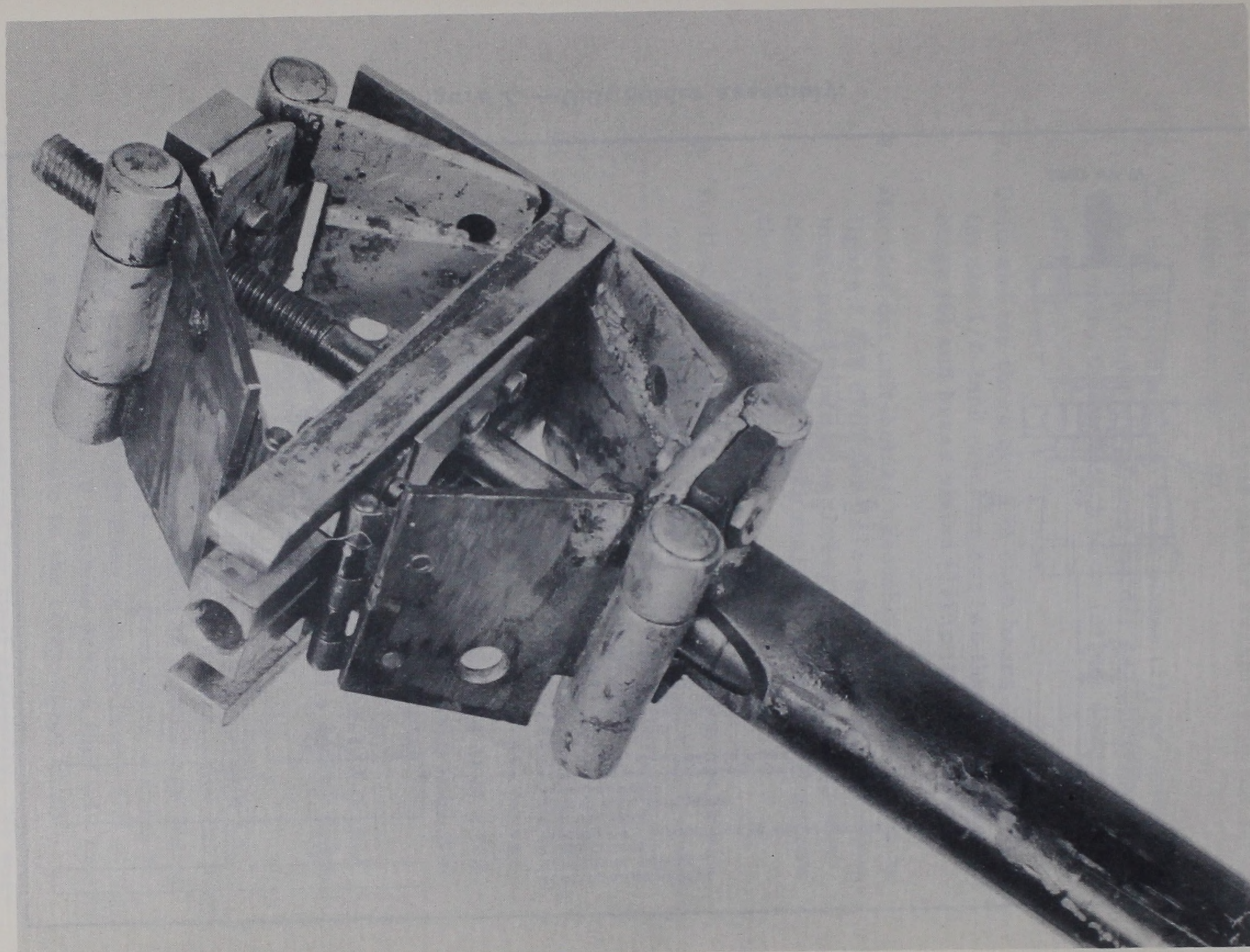

Figure 1.--Inserter for fiberglas soil-moisture units.
(Photo by Waterways Expt. Station, Corps of Engineers)

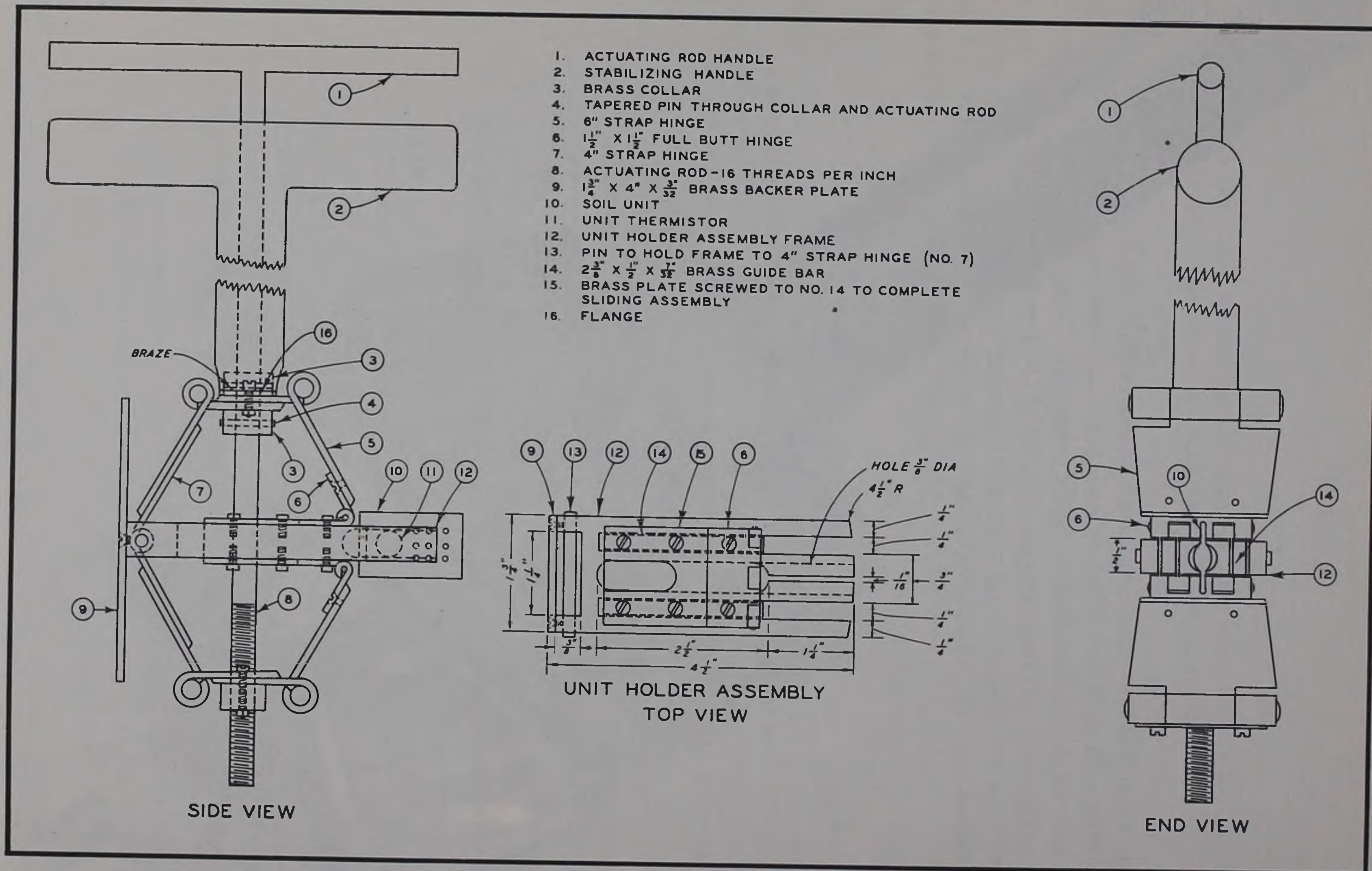

Figure 2.--Unit holder assembly.

the 1/8-inch flathead machine screws that fasten the butt hinges of the unit-holder assembly to the strap-hinge frame.

6. Cut out bottom and top brass plates (15) as shown in figure 2 (top view of unit-holder assembly) and drill four holes through each plate for no. 6 machine screws.

7. Drill and tap three holes in each brass guide bar (14) for the 1/8-inch machine screws that fasten the butt hinge (6) and brass plates (15) to the guide bars.

8. Machine out unit-holder assembly frame as shown in figure 2 and drill two 3/16-inch holes for the strap-hinge pin (13) to pass through. Drill and tap two holes for the 1/8-inch machine screws that secure the backer plate.

9. Drill and tap the 3/4 by 1/2 by 2-1/8-inch brass nut for the actuating rod (tap 16 threads per inch). Also, drill hole for a no. 10 machine screw through each side of nut to fasten to strap-hinge frame.

10. Drill and countersink holes for no. 6 flathead machine screws in backer plate (9).

11. Cut the 1-inch brass rod stock in two and drill a 3/8-inch hole through the center of each half; then drill a hole through the side for a tapered pin.

12. Thread 16 threads per inch on the last 3-1/2 inches of the 3/8-inch actuating rod and weld a 6-inch T-handle to the opposite end of the rod.

13. Construct a stabilizing handle with a 7/16-inch hole drilled through the top of the T-handle. Cut out pipe end as shown in figure 2 to fit in strap-hinge frame. Braze on pieces of 1/4-inch steel plate to form a flange (16). Drill the flanges at the lower end of the handle for the no. 10 machine screws that will fasten the stabilizing handle to the strap-hinge frame.

14. Material is now prepared for final assembly. No special instructions are necessary in this phase.

Table 1.--List of materials for the fiberglas unit inserter

Number required	Item
1	3/8" Steel rod for actuating rod and handle. Any desired length (1) 1/.
1	1" Metal pipe for stabilizing rod and handle. Any desired length (2).
4	6" Strap hinges.
1	4" Strap hinge.
2	1-1/2" x 1-1/2" butt hinges.
1	4-3/8" x 1-3/4" x 1/2" steel plate (12).
2	7/8" x 7/8" x 1/4" steel plate (16).
1	1-3/4" x 4" x 3/32" brass plate (9).
2	1-1/2" x 1-1/2" x 1/16" brass plates (15).
1	2-1/8" x 1/2" x 3/4" brass nut for actuating rod.
1 inch	of 3/4" brass rod for two brass collars (3).
2	2-3/8" x 1/2" x 7/32" brass bars (14).
12	No. 6 by 3/8" machine screws, fillister head.
4	No. 10 by 1" machine screws, fillister head, with nuts.
6	No. 6 by 3/8" machine screws, flat head.
1	3/16" x 2" steel pin.
2	No. 3/0 by 1" steel taper pins.

1/ Numbers in parentheses refer to figure 2.

Operation

Operation is quite simple. To place the soil-moisture unit in the holder, lay the temperature, moisture, and ground wires alongside the unit and push the unit into the holder. The end of the unit case from which the wires emerge should be on the inside of the inserter. After the unit is in place, lower the inserter into the auger hole to the desired depth--which can be marked on the handle. Turn the actuating handle clock-wise until the unit is completely embedded in the soil. To release the inserter from the unit, turn the handle back about six turns and pull up carefully. At depths where the insertion of the unit cannot be observed, predetermine the number of turns necessary to embed the unit completely.

SWITCH SHELTERS FOR USE WITH SOIL-MOISTURE UNITS

E. H. Palpant, John L. Thames, and Austin E. Helmers

One of the chief problems in the use of electrical instruments for measuring soil moisture is that of insulating field installations against moisture, so that accurate readings may be obtained. This paper describes general experience with two types of switch shelters and a portable switch, and gives details of their construction. These shelters have been used in conjunction with fiberglas soil moisture units and should serve equally well with similar types of instruments.

Fiberglas units are seldom used singly. More often a series of units is installed at various depths throughout the part of the soil profile that is occupied by roots. At the Vicksburg Infiltration Project, 210 units were installed in stacks of 8 and 10 units each. To facilitate daily readings, groups of units were wired to a multiple-pole selector switch.

Wooden Shelters

The wooden shelter was the first type to be constructed. The first ones measured approximately 8 by 10 by 12 inches and had sloping roofs and hinged doors. The switch and terminal posts were mounted on a masonite panel and recessed about one inch into the box. This type of shelter, where placed above-ground, has performed satisfactorily at Vicksburg since April 1951.

In a later model, to facilitate construction and shipping, the size was reduced to approximately 6 by 6 by 5 inches. Dimensions and details of construction are given in figure 1. The door, which may be hinged either to the bottom or the side, displays on its inner face pertinent data as to unit numbers and depths. The bottom between post and door is 1 by 1 by 4 inches; the space between the post and back is left open for unit lead wires or cable. A panel--masonite or plywood cut to fit the front opening and anchored to the post--holds the switch and the three brass bolts that are used as terminals. Lead cable from switch to ground may be protected by metal conduit or hardware cloth. The shelters are painted but not otherwise treated. Eighteen of this type are installed at various sites in Texas and Missouri.

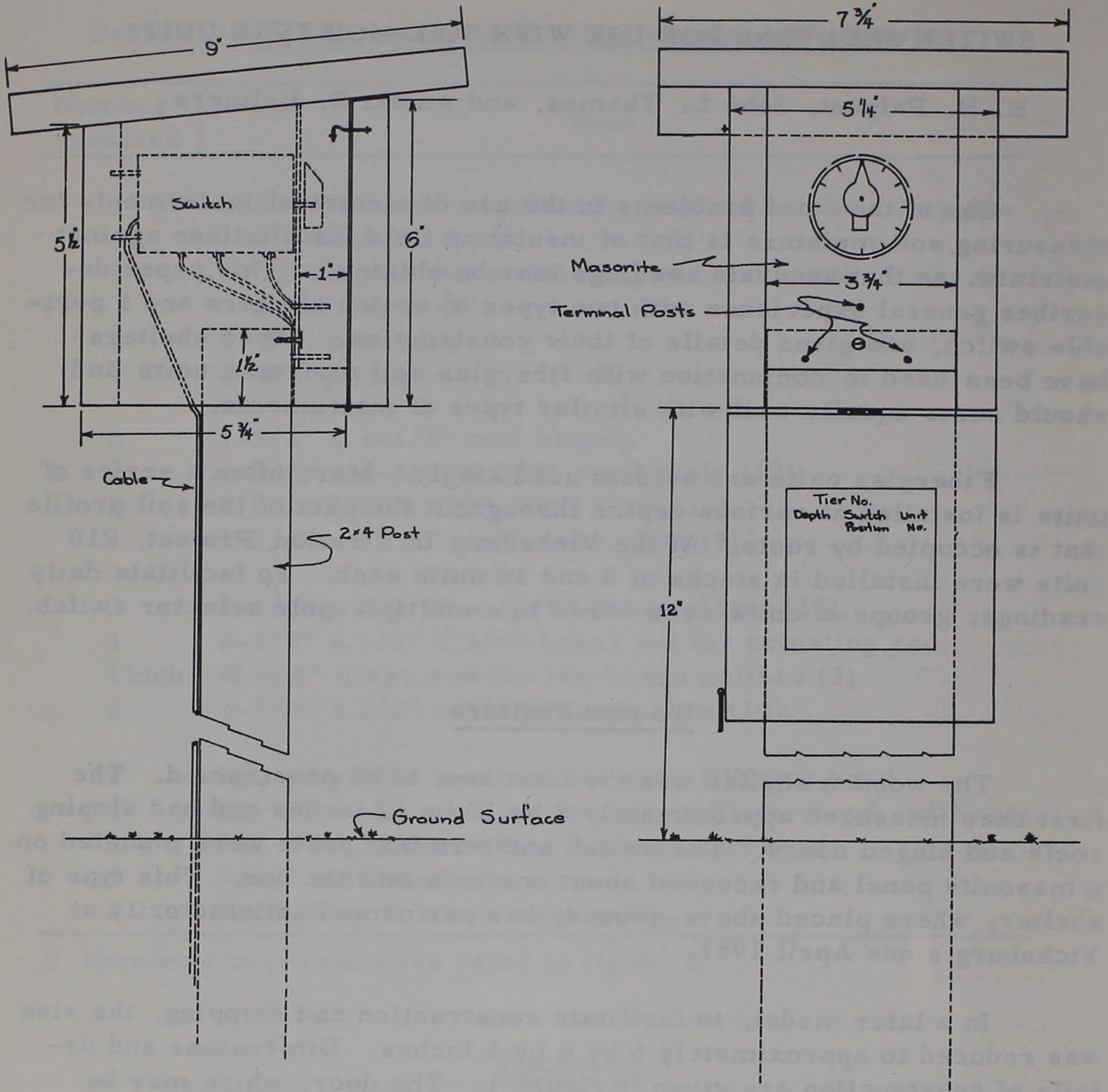

Figure 1.--Details of wooden switch shelter.

Plexiglas Shelters

The necessity for installing some of the multiple swtiches below-ground led to the development of a waterproof container made of Plexiglas[1/]. Plexiglas is easily worked, and, being transparent, it affords

1/ Plexiglas was the only plastic tried. Its use does not imply a recommendation over other plastics with simiilar qualities.

a quick check of switch connections if any unit fails to operate.

The Plexiglas shelter has been in use at Vicksburg since September, 1951. Installed below ground in a wooden box, the Plexiglas tube kept the switch dry when the inside of the box was wet by moisture from rainfall or dew. On October 2, 1951, data were obtained through a dry switch in a waterproof shelter and an unprotected switch wetted by condensation. Each switch was connected to 8 units. Condensation caused the temperature readings from the unprotected switch to be higher for units at all soil depths except three; moisture contents were from 0.1 to 10.6 percent higher at all depths. These data illustrate the necessity of keeping the switches dry.

On a few occasions when soils were saturated, the wooden box filled with water and the waterproofing failed around the openings for the cable and switch knobs in the Plexiglas housing. In later use of the Plexiglas shelter, it was installed above the ground and has worked satisfactorily.

Construction.--The housing is a Plexiglas tube sealed at both ends and containing a multiple contact switch (fig. 2). A cable that connects the switch to the units, and lead wires that connect with the meter plug, enter the housing from the back. The switch shaft extends through the front.

Procedure for assembling the housing follows. Reference to figures 2 and 3 and to the list of materials (table 1) should clear up points not mentioned.

1. From a sheet of 1/8-inch Plexiglas, cut two disks, each 2-1/2 inches in diameter. Drill a 5/8-inch hole through the center of one disk and a 11/32-inch hole through the center of the other.

2. In the disk that has the 11/32-inch hole, drill another hole off-center; this hole should be large enough to permit the lead wires to pass from the switch to the Amphenol socket into which the Colman meter is connected.

3. On the switch, file 1/16-inch from the side of each gang

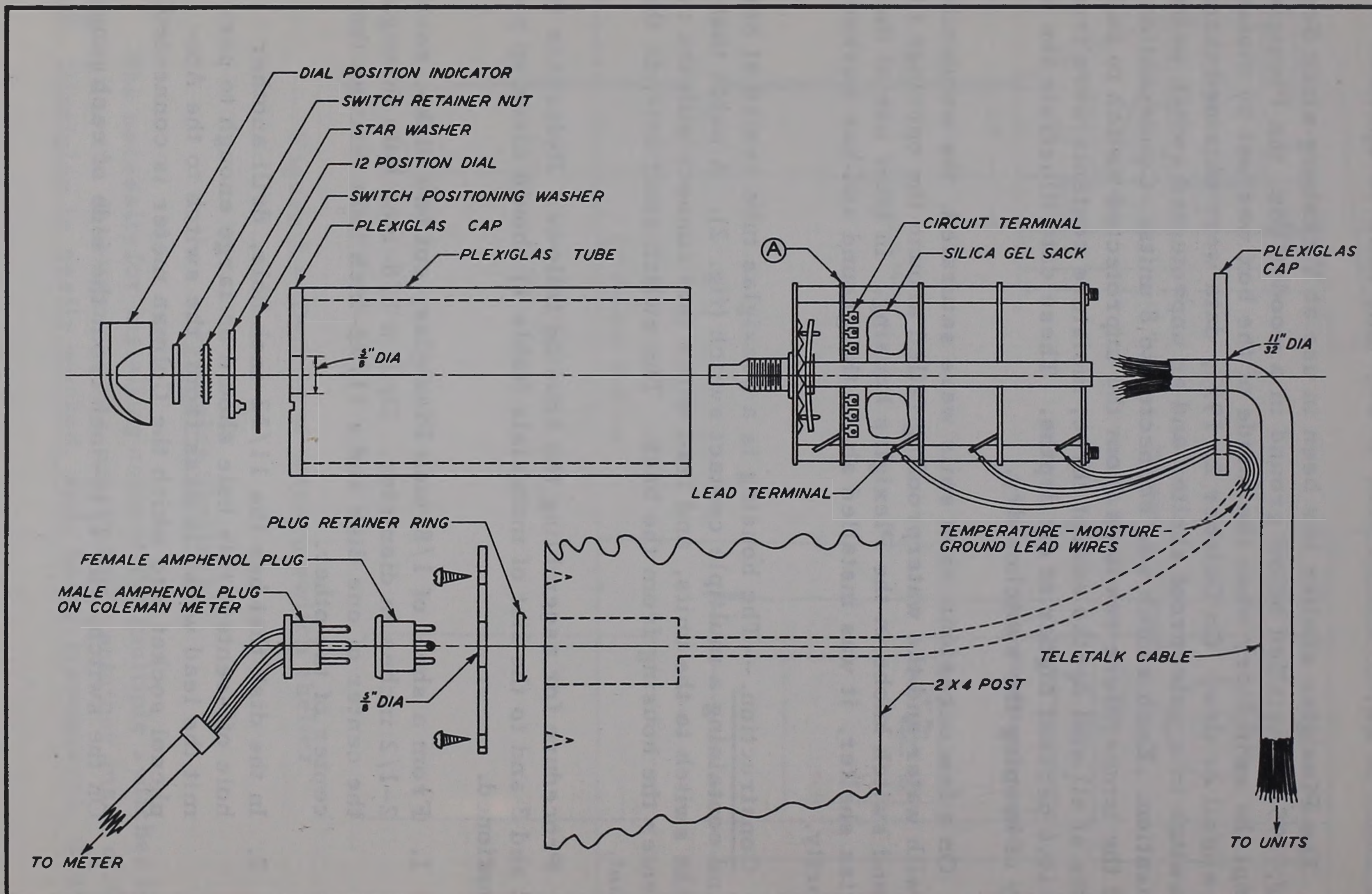

Figure 2. --Exploded view of waterproof switch housing.

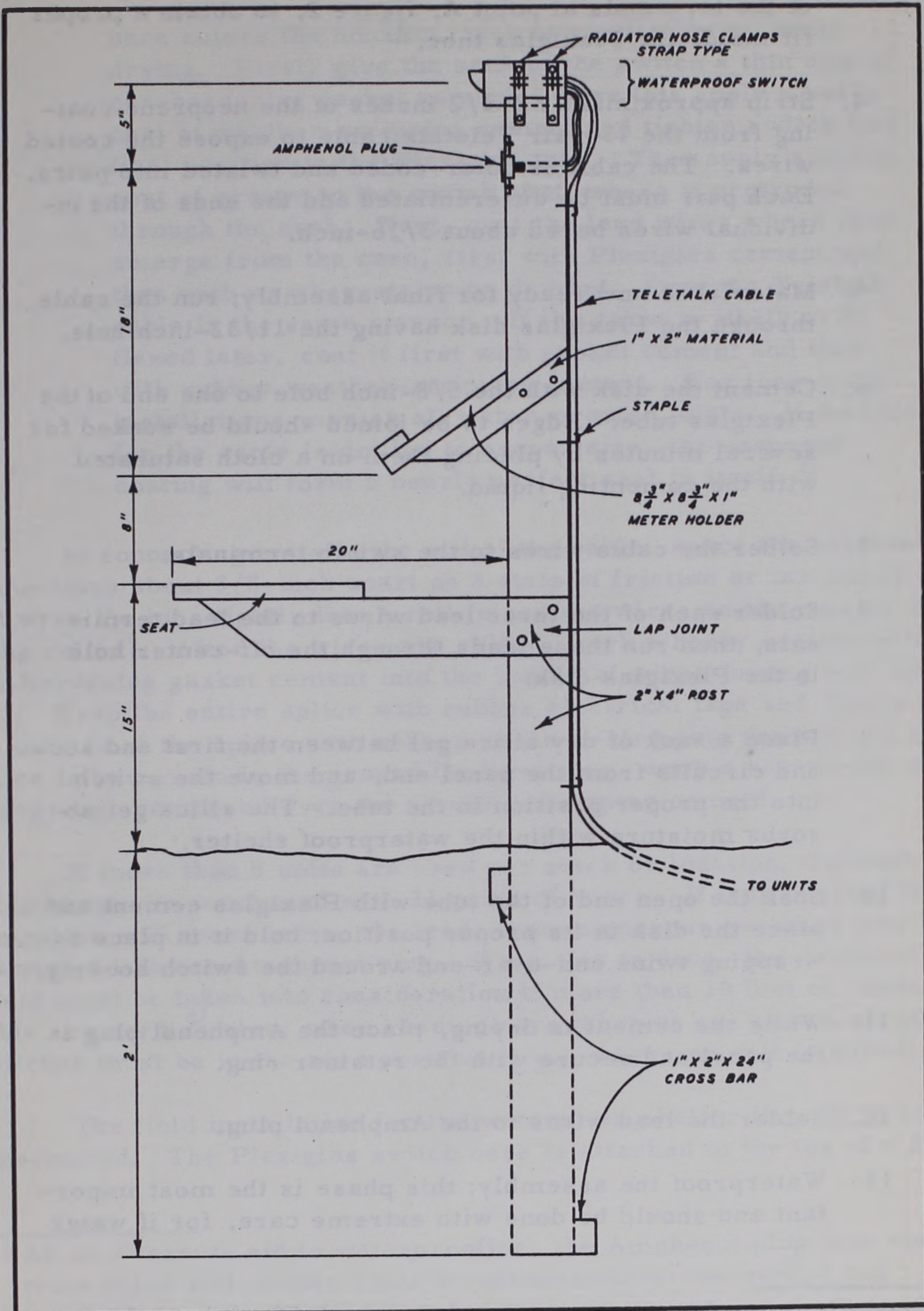

Figure 3. --Field installation of waterproof switch.

of the terminals at point A, figure 2, to obtain a proper fit inside the Plexiglas tube.[2]

4. Strip approximately 3-1/2 inches of the neoprene coating from the 13-pair Teletalk cable to expose the coated wires. The cable is color-coded and twisted into pairs. Each pair must be differentiated and the ends of the individual wires bared about 3/16-inch.

5. Material is now ready for final assembly; run the cable through the Plexiglas disk having the 11/32-inch hole.

6. Cement the disk with the 5/8-inch hole to one end of the Plexiglas tube. Edges to be joined should be soaked for several minutes by placing them on a cloth saturated with the cementing liquid.

7. Solder the cable wires to the switch terminals.

8. Solder each of the three lead wires to the lead terminals, then run these leads through the off-center hole in the Plexiglas disk.

9. Place a sack of dry silica gel between the first and second circuits from the panel end, and move the switch into the proper position in the tube. The silica gel absorbs moisture within the waterproof shelter.

10. Soak the open end of the tube with Plexiglas cement and place the disk in its proper position; hold it in place by wrapping twine end-over-end around the switch housing.

11. While the cement is drying, place the Amphenol plug in the panel and secure with the retainer ring.

12. Solder the lead wires to the Amphenol plug.

13. Waterproof the assembly; this phase is the most important and should be done with extreme care, for if water

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2/ Recently it has been learned that 2-3/4-inch Plexiglas tubing is available. Tubing of this size would eliminate the need for step 3.

once enters the housing, lack of ventilation prevents drying. First, give the neck of the switch a thin coat of non-hardening gasket cement. Over this apply a heavy coat of weather-stripping cement and tighten switch into final position in the Plexiglas tube. Then apply a heavy coat of grease to the switch shaft where it protrudes through the neck. Next, coat the lead wires where they emerge from the case, first with Plexiglas cement and then with weather-stripping cement. Coat the Teletalk cable in the same manner. If the cable is likely to be flexed later, coat it first with gasket cement and then with rubber weather-stripping cement. For long-term installations varnish all water-proofed joints. If the hole for the cable is drilled to proper size, the neoprene coating will form a nearly perfect seal in itself.[3/]

In connecting units to the end of the cable, space the soldered connections about 3/8-inch apart on a strip of friction or insulating tape and wrap the tape tightly into a roll (place the wires on the tape as it is being rolled). After the wires are rolled, work a heavy coating of the non-hardening gasket cement into the bundle of wires joining into the roll. Wrap the entire splice with rubber electrical tape and finally coat the outside of the splice with rubber weather-stripping cement. If the splice is to remain in the ground for very long, work a heavy coat of wax-grease compound over the weather-stripping cement.

If more than 8 units are used per stack or location, Teletalk cable should be purchased with 21 pairs of wires. If it is desired to centralize still more units, the leads from numerous switches may be channeled into one Amphenol plug. When this is done, the condenser effect must be taken into consideration if more than 10 feet of conductor cable are used;[4/] also, when readings are taken at one switch all other switches must be in the zero position (i. e., where no unit is wired).

The field installation for the waterproof shelter (fig. 3) is easily constructed. The Plexiglas switch case is attached to the top of a 2 by 4

3/ As an alternate aid to waterproofing, the Amphenol plug with contacts filled with solder could be substituted for the socket and mounted directly into the housing.

4/ Colman, E. A. Manual of instructions for use of the fiberglas soil-moisture instrument. Calif. Forest and Range Expt. Sta., 20 pp. 1947 (rev. 1950).

Table 1.--Materials for waterproof switch[1]

Amount required	Item
6 feet	13-pair Teletalk cable: or any desired length less than 10 feet. (Cable may be purchased through Webster Electric Co., Darnold and Weichers Sts., Racine, Wisconsin; or Graybar Electric Co., 1547 Graybar Bldg., New York City 17, N. Y.)
1	Plexiglas sheet, 1/8 inch thick, for two disks 2-1/2 inches in diameter.
1	Plexiglas tube 5 inches long and 2-1/2 or 2-3/4 inches in outside diameter; walls 1/8 inch thick. (Plexiglas available through Rohm and Haas Co., Bristol, Pa.)
	Plexiglas cement.
1	Mallory switch no. 1231L (shorting type) or no. 1331L (non-shorting). Their equivalents in Centralab switches are nos. 1422 and 1423.
1	Yaxley dial (12 positions) or Mallory no. 35 and Centralab no. P-118 (11 positions).
1	Female Amphenol socket no. 78-S6S, 6 terminals (remove 3); or no. 3106A-10 SL-3S, 3 terminals.
1	Male Amphenol plug no. 71-6S, 6 terminals (remove 3); or no. 3107C-10 SL-3P, 3 terminals.
3	Lead wires: 18-inch pieces of fine radio wire or wire from Teletalk cable. (Switches, dials, and plugs are available at radio repair shops.)
1	Panel for the outlet Amphenol plug--1/16-inch sheet metal 1-5/8 inches wide and 2-1/2 inches long.
2	Roundhead wood screws for fastening panel to post.
1	Roll of solder.
	Gasket cement and weather-stripping cement.
	Rubber electrical tape or friction tape.

1/ The tools needed for constructing the switch cover are a soldering iron, coping saw, drill with countersink and other bits, long-nose pliers, jackknife, file, adjustable wrench, and vise.

post. To the post is also fastened a meter holder and seat. When taking a series of meter readings, the field man simply plugs in the meter to the Amphenol plug and reads any unit by changing the position of the switch. For convenience, a permanent record of the depth, number, and dial position of each unit is placed on the switch post.

Portable Switch

A switch that can be carried with the meter and plugged into a socket at the field installation is presently being tested. As shown in figure 4, this device consists of a multiple-point plug to which is attached a selector switch. The switch in the figure is protected by aluminum tubing, but Plexiglas can be used. Waterproofing is not necessary. In the first model to be tested, the plug was not sturdy enough to withstand continuous use. Currently a 35-contact plug with matching socket (Amphenol parts AH 3106 B-36-15p and AH 3100 B-36-155) is being tried.

In constructing the portable switch, slight alterations in switch and plug are necessary. On the switch, spaces between gangs are shortened by half and the casing of the plug is drilled to receive the small

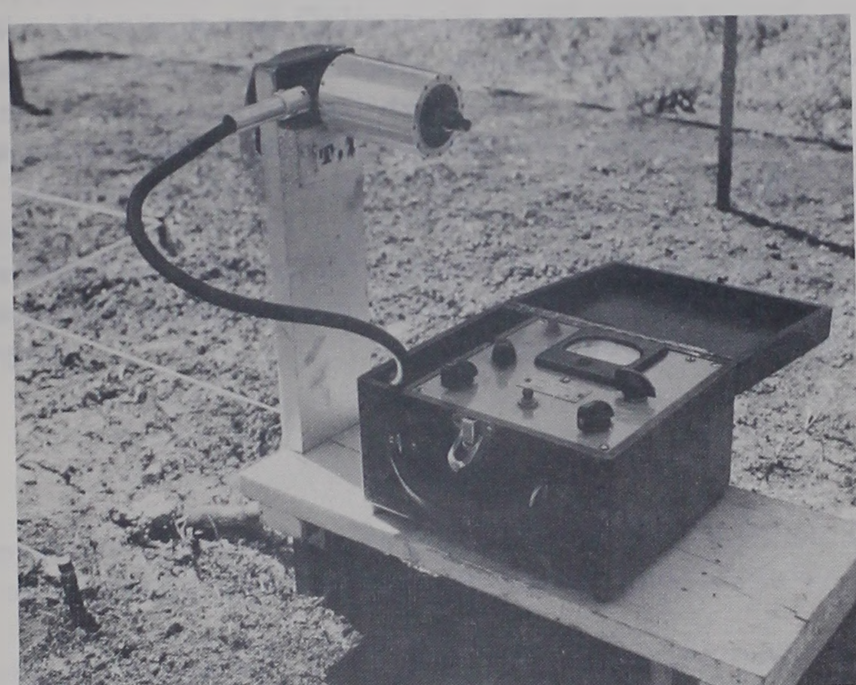

Figure 4.--Portable switch connected to socket on field installation.

Amphenol socket. After the switch housing has been bolted to the back of the plug cover, the plug contacts are wired directly to the switch through the end plate. Terminal contacts of the unit leads in the socket must match contacts of the switch plug.

At the socket on the post, ground leads from the moisture units are wired to a common contact. Temperature and moisture leads are wired to separate contacts.

At the plug, a corresponding ground contact is wired directly to the Amphenol socket. Corresponding moisture and temperature contacts are wired to the selector positions of the separate moisture and temperature gangs. Selector leads from each gang are then connected to the Amphenol socket.

Discussion

The exposed switch in the above-ground wooden shelter has produced a continuous and reliable record. Materials for its simple construction are readily available. Little maintenance other than painting is required, and cost on small installations is less than that of the other types.

Where snowfall or rains are heavy, or where the switch must be placed below ground, a waterproof installation, such as the Plexiglas housing, would be required. Although its construction is more detailed and maintenance is necessary, the waterproof switch should meet those conditions nicely.

On large installations of many stacks, the portable switch with a sturdy plug would prove the cheapest and simplest to install once the switching unit had been constructed.

MOISTURE EQUILIBRATION IN NATURAL CORES DURING LABORATORY CALIBRATION OF FIBERGLAS SOIL-MOISTURE UNITS

Charles A. Carlson

One of the major problems with the use of electrical soil-moisture units is the development of an accurate calibration for converting electrical resistances to soil moisture contents. Various procedures have been proposed for laboratory calibration (1, 2, 3, 4, 5, 6), but at the Vicksburg Infiltration Project laboratory calibration did not prove sufficiently accurate to supplant field calibration. One reason lies in the difference in the way the soil dries in the field and in the laboratory. In the field, the absorption of water by the root network is fairly uniform throughout the soil near the unit. In the laboratory, drying is achieved by evaporation from the soil surface, with the result that soil moisture content near the unit is greater than at the surface of the sample.

To reduce this moisture gradient, various workers have kept the sample in a humid chamber following each drying period so that a moisture redistribution could occur. Cummings and Chandler (4) used a 12-hour equilibration period, Kelley (6) recommends 19 hours. Colman (3) followed Kelley's recommendation. In these tests sieved soil was used. More recently, Hendrix and Colman (5) used cores of natural soil, 3 inches in diameter by 2 inches high, equilibrating overnight as before.

Although the fiberglas soil moisture units are calibrated in the field on the Vicksburg Infiltration Project, limited laboratory calibrations were made using natural soil cores following, in general, the methods outlined by Colman. During this work, the necessity for the equilibration of the cores was studied. The results are reported in the following pages.

Methods

Laboratory calibrations using soil cores of natural structure were made on Grenada and Collins silt loams and Commerce clay.

To obtain the cores, fiberglas soil moisture units were inserted at the required soil depth in the face of a pit or auger hole. The cylinders were prepared by removing both ends from some lacquered cans that were 2-5/8 inches in diameter and had been cut down to 2 or 3 inches in height. These cylinders were pressed into the soil around the units

and dug out with no apparent disturbance of the core; the soil then was cut flush with the ends. The cores were retained in the cylinders throughout the test.

Three series of calibrations were conducted. In the first, 10 cores, three inches long, of Collins silt loam were used. The base of each core was covered with a cheese cloth disk and bound with 16-mesh copper screen tied with monel wire. After air-drying, the cores were saturated from the bottom with distilled water and soaked for three days. Meter readings of units were taken with the cores soaking in water. The cores were then removed from the water, weighed, dried in the air for several hours, and placed in a humid chamber overnight. The relative humidity was maintained at 98 percent by a saturated solution of lead nitrate covering the bottom of the desiccator chamber. After the overnight treatment, the core weight and the unit resistance were determined. The sequence of drying, equilibrating, and measuring resistance and weight was repeated several times.

When the moisture content approached the wilting point, the cores were kept in the chamber for 5 days in order to determine the effect of an extended equilibrating time on the calibration curve. Resistance and weight were measured occasionally, but with no drying treatment. This was followed by a drying period and a second extended equilibration, this time for 16 days. Resistance and weights were again measured periodically. Resistances were plotted against gross weights of the samples.

In the second calibration, 52 two-inch cores from all three soils were used. Three sections, about 3/4 by 1-1/2 inches, were cut out of the side of each can to assure more uniform drying. A double layer of cheesecloth was wrapped around the can to retain the soil. Again the wetting and drying sequence with equilibration was followed. For two intervals of 6 days each during the drying cycle, resistances were measured without opening the humid chamber: the wires of the units passed through slits in a sponge rubber gasket fastened to the rim of the chamber upon which the lid rested. The cores were not weighed during these intervals. At the conclusion of the calibration, the oven-dry weights were determined and moisture contents calculated.

In the third series, 28 two-inch cores of Grenada silt loam were used with no sections removed from the side wall of the cans. The procedure of the second series was followed except that periodically measurements were taken before as well as after an overnight equilibration period.

To determine moisture distribution within the cores, separate cores were taken without soil moisture units, in cylinders of the same dimensions as those containing the units. The calibration sequence of saturating, drying, and equilibrating overnight was followed until the moisture content was less than field capacity. Comparisons were made between soils, core length, side-wall openings, humidity of the equilibration chamber, and continuous air-drying. All cores were then sectioned into six approximately equal layers and their moisture contents determined. Treatments were made in duplicate.

Results and Discussion

During the two prolonged periods in the humid chamber with the first calibration series, the resistance varied with moisture content proportionately the same as with the standard treatment of air-drying and overnight equilibration (fig. 1). This indicates that conditions within the chamber resulted in drying rather than equilibration.

With the extended equilibration of the second series, any chance drying was eliminated during the time resistance measurements were taken, since the cores were not removed from the chamber. The resistance increased at a constant rate (fig. 2), thereby indicating a constant rate of drying in the humid chamber.

Measurements of the third series before and after equilibration are graphed in figure 3. The actual moisture content of a core is plotted against its moisture content derived from the unit resistance in the core and its field calibration curve. With perfect agreement between laboratory and field data, all points would fall on the line. With true equilibration in the humid chamber, the points would shift horizontally. The diagonal shift following the humid chamber treatment indicates drying. Further, the shift does not necessarily improve agreement between the laboratory and the field calibrations.

Further evidence showing that equilibration does not occur was found by cross-sectioning the cores. Comparisons between core length, slots in the side-wall of the can, humidity of the equilibration chamber, and continuous air-drying are shown in table 1. Regardless of the treatment of the core, variation in moisture persists, with the center of the core remaining wetter than the ends. The most uniform moisture distribution is found in the cores kept in the saturated atmosphere overnight and in cores with slotted sides. The greatest range in moisture content is found in the three-inch cores. The clay soil has a greater range than the silt loam soil with all treatments, particularly in three-inch cores.

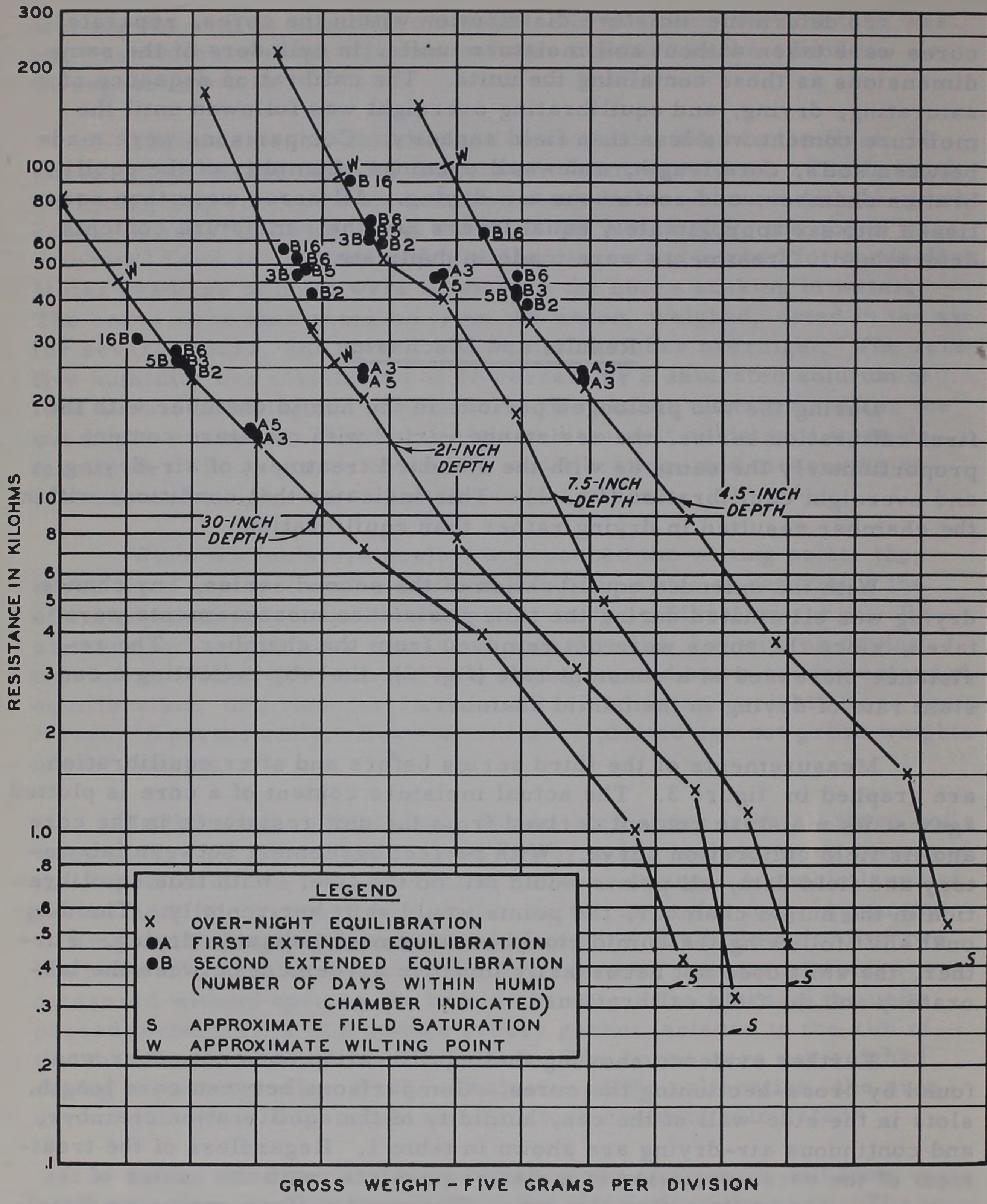

Figure 1.--Extended equilibration of soil cores in humid chamber. Cores were of Collins silt loam and 3 inches long. The curves are displaced laterally, to prevent them from overlapping.

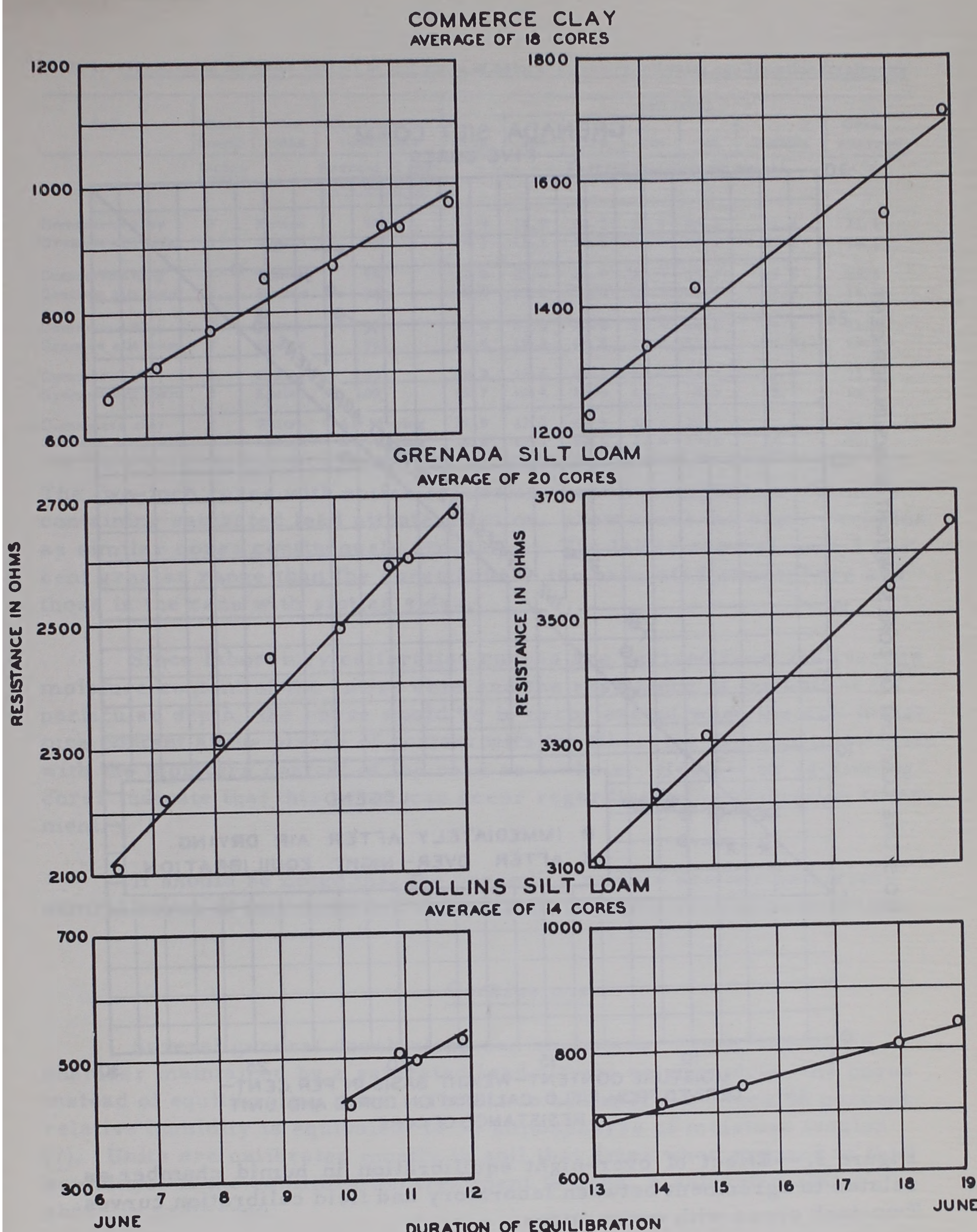

Figure 2.--Change in unit resistance with time of undisturbed cores in the humid chamber. Two-inch cores with slotted sides.

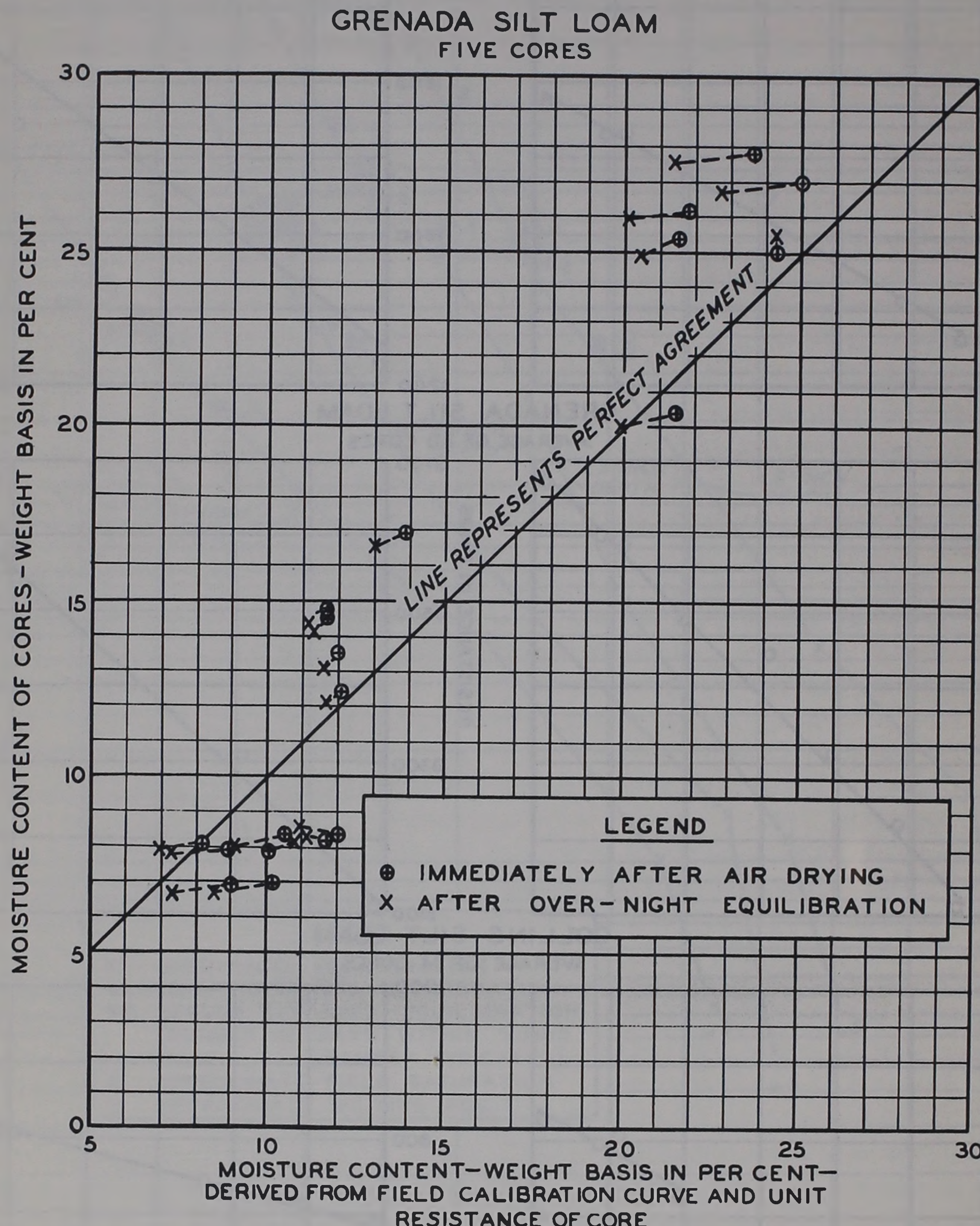

Figure 3.--Effect of over-night equilibration in humid chamber as related to agreement between laboratory and field calibration curves. Two-inch cores with entire sides.

Table 1. —Variation of moisture content in soil cores of natural structure following equilibration treatments

Soil	Core length	Can sides	Equilibration conditions	Soil layer						
				Top	2nd	3rd	4th	5th	Bottom	Core average
	Inches		Percent of relative humidity	- - - - - Percent moisture by weight - - - - -						
Commerce clay	3	Entire	98	13.9	18.9	22.7	22.7	25.2	21.5	21.1
Grenada silt loam	3	Entire	98	13.1	15.1	17.4	18.1	17.5	17.2	16.6
Commerce clay	2	Slotted	98	22.0	25.0	25.9	25.4	24.7	25.8	24.5
Grenada silt loam	2	Slotted	98	18.8	19.1	19.0	19.7	20.1	21.3	19.6
Commerce clay	2	Entire	98	19.2	21.4	22.0	22.0	22.0	21.1	21.2
Grenada silt loam	2	Entire	98	14.6	15.2	15.8	16.5	15.2	14.7	15.4
Commerce clay	2	Entire	100	20.3	21.8	22.0	22.2	22.2	21.2	21.6
Grenada silt loam	2	Entire	100	15.7	16.4	16.5	16.4	16.3	15.1	16.0
Commerce clay	2	Entire	Air-drying	18.9	22.3	23.9	24.2	24.1	23.4	22.8
Grenada silt loam	2	Entire	Air-drying	15.6	17.1	17.6	17.8	17.3	15.3	16.8

The two-inch cores with entire sidewalls, kept overnight in a chamber containing saturated lead nitrate solution, show about the same variation as similar cores continuously air-dried. The latter show about a 1 percent greater range than the cores kept in the saturated atmosphere and those in the cans with slotted sides.

Since laboratory calibration curves are derived from the average moisture content of the entire core and the resistance of the unit at its particular depth, the curve would be in error except when the soil moisture content at the places of contact with the fiberglas happens to coincide with the moisture content of the core as a whole. Results by sectioning cores indicate that this error can occur regardless of equilibration treatment.

It should be noted that the preceding results are derived from natural cores of fine-textured soils tested in humid climatic conditions.

Conclusions

Several general conclusions can be drawn. First, the humid chamber maintained by a saturated lead nitrate solution dries the cores instead of equilibrating them. This is to be expected, since 98 percent relative humidity is equivalent to 30 atmospheres of moisture tension (7). Units are calibrated mostly in soil that dries when exposed to this humidity. If the equilibration treatment is used, a saturated atmosphere is preferred.

Second, surface evaporation dries natural soil cores and creates a moisture gradient that remains regardless of the equilibration treatment. Vapor equilibration is too slow a process (8) to occur overnight in the humid chamber. Kelley has found that thin layers of soil can be brought to a fairly uniform moisture content during calibration (6). Results at Vicksburg show less moisture gradient in the two-inch core than in the three-inch, indicating that the shortest core that can contain the unit (which is 1-1/2 inches long) will be best. A moisture gradient may still occur, however.

Third, since laboratory calibrations have not proved sufficiently accurate to supplant the field calibration of fine-textured soils in a humid climate, the laboratory calibration is used at the Vicksburg Infiltration Project only to check the general shape and range of the curve. The small shift in the curve that results from the equilibration treatment does not necessarily improve agreement with the field calibration. For these reasons, any laboratory calibration done at this Project is conducted by continuous air-drying with periodic measurements of core weight and unit resistance.

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INSTALLATION AND FIELD CALIBRATION OF FIBERGLAS SOIL-MOISTURE UNITS

K. G. Reinhart

Successful use of fiberglas soil-moisture units depends on careful installation and calibration. The following paper summarizes the experience of almost two years of intensive work with these devices. The recommendations and suggestions are by no means final, but they may serve as points of departure for future work.

Installation

The installation of a soil-moisture measuring device of any type requires that it be placed at the desired depth in close contact with the soil with a minimum disturbance of soil and vegetation. The fiberglas unit, being small, can be pressed into the side of an excavation without causing a major change in natural conditions. The necessary excavation, however, often causes difficulties.

Methods.--At the Vicksburg Infiltration Project, the units were first installed in a pit measuring 3 by 6 by 4 feet. A small core was removed from the side of the pit, and the unit was inserted perpendicular to the ground surface in the undisturbed soil at the end of the core hole. The core was then put back into its original position. Sixteen units were inserted--eight staggered horizontally to a depth of 42 inches in each 6-foot side of the pit. The pit was then refilled, care being taken to put each horizon in its proper place, and to pack the soil as closely as possible to the original density, and to replace the sod with minimum disturbance.

There are several advantages to this method. Soil samples for laboratory testing can be readily obtained, the units can be easily placed in the wall of the pit, and the soil profile can be studied. However, the method entails disturbance of a considerable volume of soil and the vegetation it supports. The pattern of subsurface flow may be altered because it is impossible to reproduce the original permeability when replacing soil. This method is also time-consuming.

Because of these disadvantages, subsequent installations have been made in 5-inch auger holes. Units are pressed into the sidewall of the hole, unit positions being rotated 45 degrees to avoid disturbance

between units. At first, a stick with a notch cut to fit the unit was used to press the unit into the wall of the hole; later a device for mechanically inserting the unit was developed (see p. 16).

The units are placed perpendicular to the ground surface and the wires are led downward before being brought to the surface in order to prevent water movement along the wires to the units. Soil is replaced in its original position and repacked as nearly as practicable to its original density. Lead wires from the units have been wired into several different types of switch housings for ease in daily readings (p. 21). The position of the stack of units is marked for future reference.

Less time is required to install units in the auger hole than in the pit. At Vicksburg, three stacks of ten units each, with the deepest unit at 42 inches, have been installed in one day by a two-man crew using the auger-hole method. This does not include the time required to wire the units into a terminal box or switch housing.

On the whole, the advantages of the auger-hole method were judged to outweigh those of the pit method by a considerable margin.

Importance of proper installation.--The importance of careful installation of units cannot be over-emphasized. Units should be installed, if possible, when the soil is moist enough to pack well; it should be below field capacity but not dry and hard. The excavated soil must be replaced at least to its original density (2), or else an artificial channel will be created through which water will travel rapidly to the units. Such a channel is indicated when, after a rain, soil moisture samples at a given depth are still dry whereas the resistance of the corresponding unit has dropped significantly. This problem is especially serious when the natural soil has a hardpan or other layer of low permeability that is difficult to duplicate when refilling excavations.

The importance of having the soil moist was illustrated when several stacks were installed in very dry soil. Because sufficient compaction was not obtained, the soil moisture record was in error until the advent of winter rains. In more recent installations in dry soil, the auger hole has been filled with water and allowed to drain to facilitate pressing the units into the soil; enough water is added to the excavated soil to make it pack satisfactorily. Before readings can then be taken, the artificially wetted soil must dry to the moisture content of the surrounding soil.

From observations, replacing soil at too low a density can lead to unnaturally heavy root growth with the possibility of excessive transpiration drain in the vicinity of the units. The magnitude of any effect of this condition has not been explored.

Since the units are placed in natural soil adjacent to the auger hole, no harm is done if the soil in the hole is packed to somewhat more than its original density. Nonetheless, excessive tamping may cause lateral compaction of the natural soil around the units.

Protecting experimental sites from disturbance.--Trampling, especially when the units are read daily, can destroy the natural characteristics of a site. At Vicksburg, every effort has been made to minimize such damage.

Portable wooden platforms are used to protect the sampling area during installation and when obtaining calibration samples. Several feet of cable are attached to the unit lead wires so that readings can be taken without standing above the units. Walkways are designated by stakes and wire or cord in order to prevent trampling areas where bulk density or other undisturbed samples may be taken.

Where necessary, areas are fenced to keep out livestock. At one stack of units rabbits, finding the insulation palatable, chewed the above-ground portions of the wire leads. Hardware cloth, wrapped around the group of wires, prevented a repetition of the damage.

Serviceability of units and meters.--Of the 210 units installed, only 2 have failed (they shorted out). Approximately 100 have been removed from the soil after several months to a year of operation. Most appeared none the worse for wear and many have been reinstalled at other locations.

The resistance meters have been generally dependable. Battery trouble caused most failures; corrosion on the push-button switch sometimes led to erratic readings. Where daily readings are required, a spare meter should be available. After about 15 months of operation on this Project, two of the three meters that were in use were returned to the factory for reconditioning.

Field Calibration

Calibration of units is the most difficult and time-consuming job encountered, the more so since each unit must be calibrated individually.

Several workers have calibrated in the laboratory; others have relied on field measurements. Colman and Hendrix (3) (4) discuss three methods: field calibration, laboratory calibration in repacked soil, and laboratory calibration in a soil core taken from the field with a minimum disturbance of soil structure. They do not recommend calibration in repacked soil, but the other two methods gave satisfactory results.

Before a calibration procedure can be settled upon, it is necessary to decide whether the record to be obtained from a unit is to represent the average moisture in the area surrounding and containing the unit, or only at the point where the unit is installed. The distinction between these two concepts is fundamental. 1/

Under the area concept the unit is installed in or adjacent to the area it is to represent--at Vicksburg usually a plot 6 by 6 feet square. It is calibrated by drawing soil samples at random from this area and plotting the moisture contents of the samples against the resistance determined at the time the samples are taken. The resistance is an index of average soil moisture at a particular soil depth over the entire sample plot. This is a distinct advantage, because the marked deviations in soil moisture that occur even within a small area give the value for a single point little significance.

With the point concept, an attempt is made to determine the moisture content of the soil that is in contact with the unit. Since this soil cannot be directly sampled in the field without destroying the installation, laboratory calibration is indicated. The difficulty lies in obtaining a laboratory calibration that will accurately reflect field conditions--something that could not be accomplished at Vicksburg (p. 31). Even if soil moisture could be determined at the point of unit installation, several units would be needed (at any given soil depth) to arrive at an average moisture content for even a small area. Thus the area concept appears to have practical advantages in addition to the fact that more confidence can be placed in the results obtained with it.

Soil sampling area.--Each stack of units requires a soil sampling area. The soil samples must be obtained close enough to the units to represent the same moisture conditions, yet not close enough to disturb the natural soil and moisture relations at the unit. The area must be large enough to take care of repeated samplings.

1/ The author is indebted to Marvin D. Hoover of the Southeastern Forest Experiment Station, U. S. Forest Service, for pointing out the significance of this distinction.

Two designs of sampling area are in use. The first is for paired stacks of units, spaced 3 feet apart. A 3- by 6-foot sampling area, divided into 1-foot squares, is laid out adjacent to each stack. The second design is for individual stacks of units. Here, a 6- by 6-foot square is laid out with the units located in the center. This area is also divided into 1-foot squares. No samples are taken less than 15 inches from the units. The buried wires from the units to the terminal box also void a portion of the area.

The size of sampling areas depends partly on site conditions. Because of microrelief and differences in the soils and vegetation, soil moisture may vary more within a distance of a few feet in some locations than in others. Calibration is easiest when the sampling area approaches uniformity. For the 6- by 6-foot sampling area, no trend was indicated when moisture content differences in paired samples were plotted against the distance between the samples. This indicates that this sampling area is not too large.

To prevent disturbance of the soil around the units, a number of separate sample areas, possibly four, could be located several feet from the stack.

Soil moisture samples.--Soil moisture samples are taken with the King tube. This tube is metal, about one inch in diameter, and long enough to obtain samples from the desired depths (5). It provides satisfactory soil moisture samples with less work and less site disturbance than instruments that obtain cores of larger diameter. Occasionally samples obtained in bulk density or other studies are used for calibration.

Paired samples are taken from two 1-foot squares selected at random. Successive increments of soil core are removed from each sample hole; a core of 3-inch length whose mid-point corresponds to the unit depth is taken, in most instances, as representing moisture content at the unit depth. Samples are placed in 4-ounce metal cans with tight lids and taken to the laboratory for determination of moisture content.

Sampling holes are plugged with similar soil to prevent entry of water to the lower depths. The sample point is then tagged with a nail and fragment of signal cloth to prevent later sampling at the same spot. Up to four holes are allowed in any 1-foot square.

On the average, 15 to 20 paired samples, taken at moisture contents ranging from saturation to wilting point, have adequately defined

the calibration curve. After the curves have been completed, their reliability is checked by occasional additional sampling.

Best results are obtained when the moisture content of the soil approaches uniformity in all depths sampled. When rain follows a dry period, a wet front moves downward through the soil. The depth of this front may vary considerably between points only a few feet apart, and the moisture content at the unit may be different from that at either sampling point.

If samples to establish the wet end of the curve are taken when the whole soil profile is uniformly wet (as it usually is during the winter and spring at Vicksburg), one drying period of 3 or 4 weeks may provide samples throughout the remaining range of moisture content. Since the soil often dries rapidly, prompt action may be required to secure samples for the middle section of the curve.

Variation within the soil frequently causes a difference of several percent in moisture content between individuals of a pair. Inspection of the values for the soil layers just above and just below the values in question may give a clue as to whether the difference is due to error in measurement or represents true soil conditions.

Another difficulty stems from the fact that at moisture contents above field capacity, the King tube compresses the sample and probably forces out water, thus giving a moisture content lower than the true value. This probably accounts for some of the variation commonly seen at the wet end of the calibration curve.

To determine the amount of variation and factors affecting it, a study was made of the moisture content of 210 paired samples taken at various depths on one 6- by 6-foot plot. On an average, one sample differed from the other member of the pair by 1.68 percent of soil-moisture content. For a second plot of the same size, the average difference for 196 pairs was 1.81 percent. When differences between members of pairs were plotted against soil moisture content a wide scatter of points resulted, an indication that the amount of variation was independent of moisture content. A slight reduction in the spread between members of pairs was noted as the field season progressed--perhaps due to training and increased experience of the crews.

As is common with most sampling procedures, the greater the variation in soil moisture as indicated by the sample pairs, the larger the number of samples necessary to prepare an adequate calibration curve.

Calibration curve.--A calibration curve on 4-cycle semi-log paper is prepared for each soil moisture unit (fig. 1). The moisture content, in percent of oven-dry weight, is plotted on the abscissa (arithmetic). The corresponding readings on the ohmmeter are converted into resistance values by the use of tables prepared for this purpose and are then plotted on the ordinate (logarithmic). The mean moisture content and the value of each of the paired samples is plotted in order to get all available information on the graph.

Points are plotted as data are obtained. When sufficient points are present and are in reasonable agreement, the calibration curve is drawn. Drawing the curve calls for considerable judgment in weighting the points. When individual samples of a pair vary widely they are given less weight than pairs that agree closely. In general, all samples taken on days when the moisture content varied considerably from depth to depth within the profile are subject to doubt.

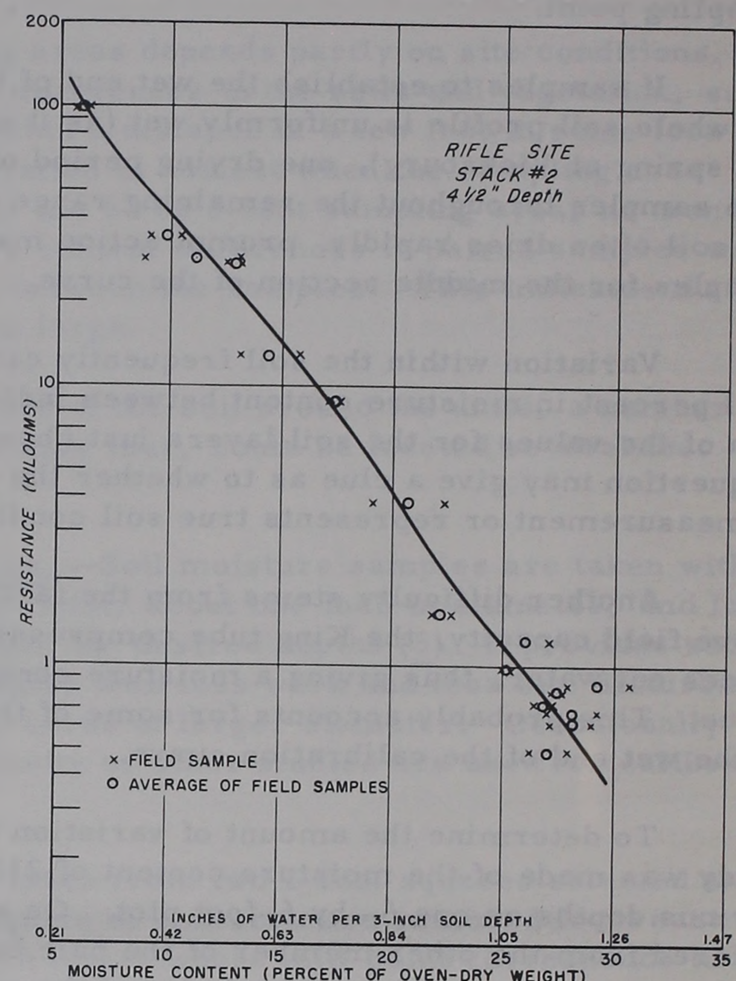

Figure 1. --Typical calibration curve.

Soil moisture content as used on this Project is finally expressed in inches depth of water. Oven-drying and weighing of samples provide values in terms of percent of dry weight of soil; field determination of bulk density provides the data necessary--for each depth and at each site--to convert moisture content in percent to inches depth. Calibration curves are prepared in percent, often before bulk density values have been determined, and values in inches depth are later marked on the abscissa of the graph. If curves are prepared in percent rather than in inches depth, they are not invalidated if additional samples change the estimate of bulk density.

Droughts and cracked soil. --Soil cracking upon drying was very pronounced on one of the areas under investigation (Commerce clay). When rain falls on cracked soil, the depth of wetting is extremely variable and the moisture contents of calibration samples are erratic.

Cracking often occurs at the point of unit installation, apparently because of the soil disturbance there. Thus, a stack of units may indicate an increase in soil moisture much greater than would be expected from the amount of rainfall.

Youker and Dreibelbis (5) report that ". . . following prolonged dry periods these [fiberglas] units did not respond to increases in soil moisture. Presumably there was an imperfect contact of the units with the soil under such conditions." Experience at Vicksburg has been that fiberglas units respond quickly to soil moisture increases even after record-breaking droughts.

Summary and Conclusions

From experience with the fiberglas moisture instrument on the Vicksburg Infiltration Project, the following points can be made:

1. Auger holes are preferred to pits for the installation of these units because of less disturbance to the experimental site.

2. Careful installation of units, especially a thorough packing of the soil in the auger hole, is of utmost importance.

3. Installation should be made, if at all possible, when the soil is moist enough to pack well.

4. Every effort must be made to protect the site from excessive disturbance.

5. The fiberglas unit wears well, as shown by installations now in their second year.

6. The unit can be used to determine moisture content either at a point or over a given area. For most purposes the latter approach seems the more promising.

7. For the purposes and conditions of the Vicksburg study, field calibration of units was necessary; laboratory calibration by itself could not be used.

8. The King tube provides generally adequate soil moisture samples for calibration and does so with a minimum of effort and site disturbance.

9. Calibration of the units is facilitated by the proper timing of soil sampling. The best time to sample is when the whole soil mass approaches uniformity in moisture content.

10. Natural variations in soil moisture, often amounting to several percent at any given depth over an apparently uniform plot as small as six feet square, necessarily limit the accuracy of any method of determining soil moisture content for a given area.

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